CANADIAN JOURNAL OF
AGRICULTURAL SCIENCE
(*formerly* Scientific Agriculture)

VOLUME 34 JULY-AUGUST 1954 No. 4

MOVEMENT OF MOISTURE IN UNSATURATED SOILS[1]

W. J. Staple and J. J. Lehane[2]

Soil Research Laboratory, Swift Current, Sask.

[Received for publication November 13, 1953]

ABSTRACT

Samples taken at different time intervals during the redistribution of moisture in cylinders of soil were used to determine liquid and vapour movement. Mean capillary conductivities were presented for Wood Mountain clay loam with apparent specific gravities 1.21, 1.28 and 1.33, and moisture contents 12 to 27 per cent. By converting conductivity to diffusivity, viz., to per cent moisture conducted into a 1-inch section of soil per day under a gradient of 1 per cent moisture per section, coefficients for liquid and vapour movement were plotted as a continuous function of moisture content. Movement in the vapour phase was a little lower than that calculated from vapour pressure data. The results were used to illustrate a numerical method for calculating soil moisture movement.

This paper deals with the movement of moisture in soil in which not all the pore spaces are filled with water. This includes the whole range of soil moisture contents from just below saturation to the air-dry condition. At the higher moisture contents, moisture is generally believed to move by capillarity in the liquid phase. The capillary conductivity falls off quite rapidly below field capacity, and approaches zero near the wilting point. Below the wilting point, moisture moves only in the vapour phase.

The movement of moisture through unsaturated soils is of interest to the farmer and agriculturist for various reasons. Besides being a factor in determining the field capacity of soils, unsaturated conductivity controls losses of stored moisture whether they occur by drainage below the root zone, or by evaporation at the surface. It also determines, to a large extent, the rate of penetration of water into the soil. Likewise, the effects of soil compaction on capillary conductivity are believed to be important in the germination of seed, and under certain conditions, in the efficiency of cultural treatments in conserving soil moisture.

Considering its importance to agriculture, it is perhaps surprising that comparatively few experimental data are available on moisture movement in unsaturated soils. In the United States, Gardner and co-workers (5) (6) (7) were pioneers in this field, both experimentally and theoretically. They showed how conductivity coefficients could be obtained, and found that conductivity increased with soil packing up to a maximum, then decreased. Recently they published an analysis of soil moisture movement

[1] Contribution from Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, Department of Agriculture, Canada.
[2] Physicist and Soil Physicist, respectively.

from a radial source. Richards and his associates (13) (14) (17) measured the capillary conductivity of disturbed soil in the moisture range from saturation to near field capacity. In England, Childs and Collis-George (3) measured the conductivity in sands throughout the capillary range, and developed a method whereby conductivities could be calculated from the moisture characteristic or release curves of porous materials. Klute (10) demonstrated a numerical method for calculating the change in soil moisture profiles from conductivity data.

Diffusion through soils in the gaseous or vapour phase was studied by Smith and Brown (18), Penman (12), Taylor (19) and Van Bavel (20). These authors agreed, in general, that the diffusion coefficient for movement through porous material was approximately 0.6 times the product of the diffusion coefficient through air and the pore space. The effects of temperature on movement of moisture, in both the liquid and vapour phases, were measured by Bouyoucos (2), Gurr *et al.* (8), and by Jones and Kohnke (9).

The redistribution of moisture in soil is a slow, continuous process which usually involves some change of moisture content at all depths throughout the soil profile. In order to estimate moisture movement under dry-land conditions, it is necessary to know the moisture conductivities for the whole moisture range from saturation to air-dry soil. The measurements presented here were made on disturbed soil under isothermal conditions, and hystersis effects were neglected. Despite these limitations it is believed that the data presented, and the methods used, are applicable to many problems of moisture movement in cultivated soils.

MATERIALS AND METHODS

Most of the measurements were made on surface samples of Wood Mountain clay loam which had a field capacity of 22 per cent and a wilting point of 9 per cent. The method for measuring conductivity consisted in packing air-dry soil into cylinders 9 to 15 inches tall, adding 0.75 to 3 inches of water and sampling the soil at intervals of 1 to 4 days for a period of 2 weeks. Differences in moisture content at successive intervals were used to calculate the conductivity.

The cylinders used in much of this work were similar to those of Bodman and Colman (1). They were built up of rings 2.25 inches in diameter and 0.5 inch high, clamped rigidly in place during the initial filling, then for sampling they were readily separated by a diaphragm to cut the soil into 0.5-inch sections. The cylinders were filled as uniformly as possible, different densities being obtained by varying both the quantity of soil added between tampings and the amount of tamping. After water was added, the cylinders were sealed to prevent evaporation, and stored in a basement room at a uniform temperature of approximately 70° F.

Typical moisture profiles obtained at periods of 1 hour, 24 hours, 4 days and 12 days after adding 0.75 inch of water to the air-dry soil are shown in Figure 1. As the moisture moves out of the upper 2 or 3 inches of soil it appears further down at moisture contents somewhat below the field capacity. The moisture movement indicated in the lower left hand corner of the figure is attributable to vapour diffusion. The area bounded by any pair of curves above a chosen level represents the amount of moisture

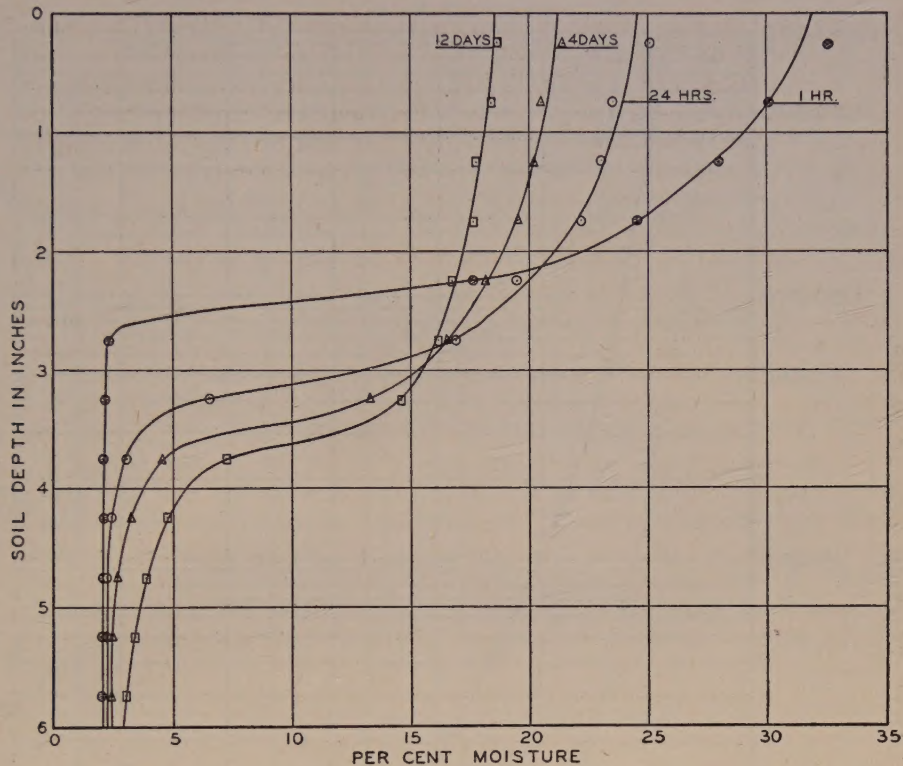

FIGURE 1. Soil moisture profiles at various time intervals after water was added to soil of apparent density 1.28.

that moves through that level in the time interval represented by the bounding curves. Thus, by considering the areas above successive levels throughout the profile, and knowing the density of the soil, the moisture movement at different moisture contents can be calculated. This movement can be converted to capillary conductivity by dividing the moisture moving past each level by the pressure gradient at that depth. This gives mean conductivities throughout the entire moisture range, the amount of data depending on the finite number of depth and time increments possible in the sampling. The method is subject to some error because of difficulty in obtaining uniform packing in all soil sections. The latter is perhaps not as serious as it would appear, because variations in apparent soil density exist under field conditions, and a fair average is all that can be hoped for.

In order to convert moisture gradients to pressure gradients, the capillary tensions of the soil at different moisture contents were obtained by using Richards' pressure plate (16) and pressure membrane (15) methods. At moisture contents below the wilting percentage, the tensions were computed from vapour pressure data. The latter were obtained by allowing samples of soil to come to equilibrium in atmospheres of known relative humidity over sulphuric acid solutions. The soil moisture tensions for Wood Mountain clay loam for a wide range of moisture contents are given in Figure 2.

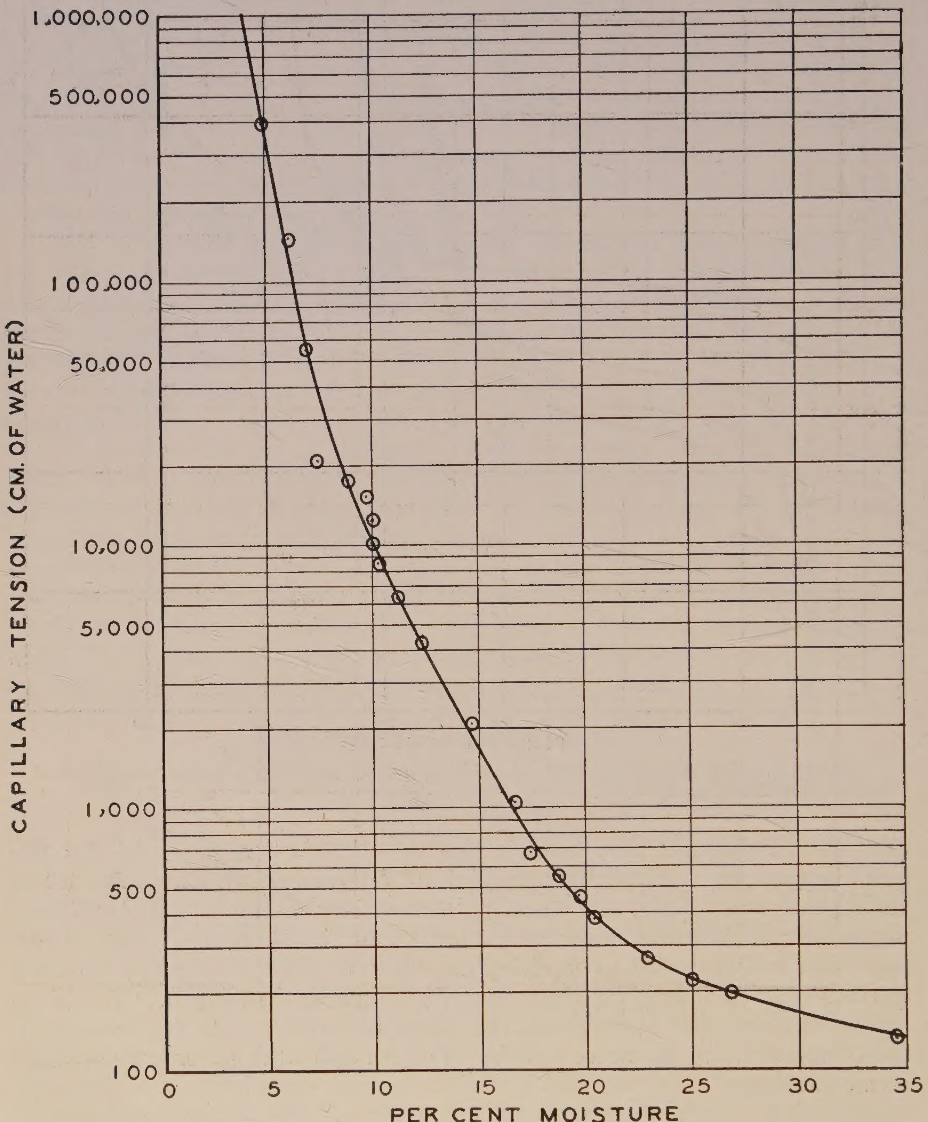

FIGURE 2. Variation of capillary tension in Wood Mountain clay loam with moisture content.

Part of the movement through wet soil was, of course, due to gravity, which was taken into account in computing conductivity coefficients.

RESULTS

Capillary Conductivity

Figure 3 shows the average conductivities obtained for three different apparent densities. The conductivity coefficient k is expressed in the

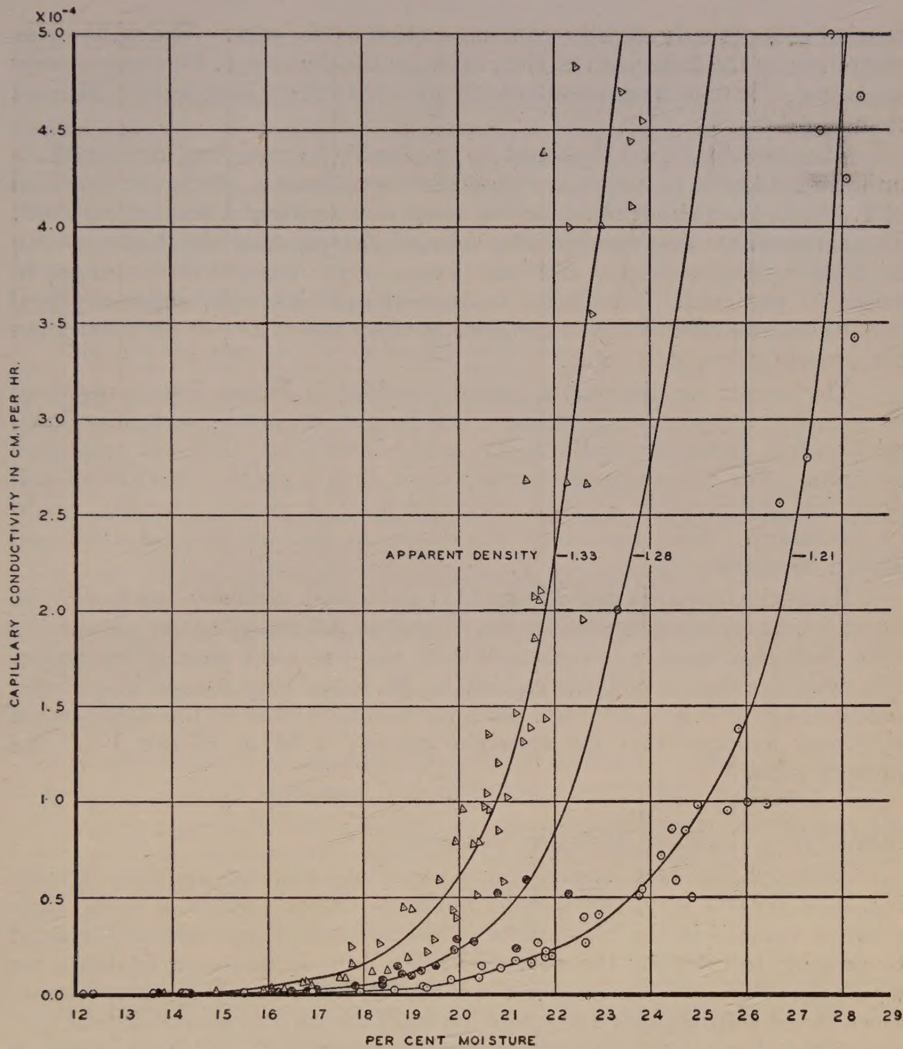

FIGURE 3. Capillary conductivity vs. soil moisture content for Wood Mountain clay loam.

practical units used by Richards and Moore (17,) namely, $k = \frac{v}{i}$ when v is the flow in cm. per hour through unit cross section, and i is the hydraulic gradient. The conductivity may be converted to c.g.s. units (cc. sec. gm.$^{-1}$) by dividing k by 3.5×10^6. The results show a rapid increase of conductivity with moisture content from a minimum near 15 per cent to high values above 23 per cent. The conductivity increases also with soil density, particularly at the higher moisture contents. This effect is noticed in the field when mulching is useful in reducing moisture loss from soil having a high water-table. The scatter at the upper end of each curve is due to the difficulty in obtaining accurate gradients when the moisture

content changes only slightly from one section to the next. The rather wide scattering at the lower end of the curve for the density 1.33 is not readily explained. It may be associated with greater swelling in some soil columns than in others.

The data in Figure 3 should be applicable to moisture movement in uniform field soils having low temperature gradients. Apparent densities of 1.3 to 1.4 are about right for the mean to a depth of 4 feet in loam soil. The curves show that conductivity falls off sharply near the field capacity at 22 per cent moisture, and that appreciable movement continues to below 15 per cent. The latter movement explains why, under dry-land conditions, the effective field capacity is often about 25 per cent less than the generally accepted value.

The results for different apparent densities in Figure 3 were obtained in separate experiments, and are insufficient to establish a functional relationship between conductivity and density at different moisture contents. For this purpose, further work with a greater number of soil densities, and possibly with an improved method of measurement, would be necessary. Also, the error introduced in the use of disturbed soil should be examined.

Recently Richards and Moore (17) published capillary conductivities for soils with moisture tensions in the range 0 to 200 cm. of water. Assuming that their clay loam was comparable to the one used here, a tension of 200 cm. of water would correspond to 26.5 per cent moisture. Their conductivity of 1.1×10^{-3} cm. per hour would be close to the value found by linear extrapolation for apparent density 1.33 in Figure 3 of the present paper.

Method for Calculating Moisture Movement

Although capillary tension and conductivity data are useful in explaining, in a general way, the various moisture characteristics of soils, their greatest value is in the calculation of soil moisture movement. It should be possible to calculate the movement not only at moisture contents for which the conductivities are given in Figure 3, but also at moisture contents down to the wilting point and lower. To facilitate such a calculation, the conductivities have been changed to diffusivities, viz., to the percentage increase in moisture content of a 1-inch section of soil with water entering it under a gradient of 1 per cent moisture per inch. The diffusivity D (inch^2 per day) is given by $100\ A\ \frac{\rho}{\sigma}\ k\ \frac{\delta h}{\delta m}$ where ρ is the density of water, σ is the apparent density of the soil, k is the conductivity in cm. per hour, $\frac{\delta h}{\delta m}$ is the slope of the capillary tension vs. moisture content relationship (Figure 2 on linear scale) and A is a constant to change D from cm.^{2} per hour to inch^2 per day. The use of such a unit can be criticized because it does not tell us much of the physical factors governing moisture movement. However, since both capillary tension and conductivity vary with soil moisture content in rather complicated fashion, it seems justifiable when numerical methods must be used, to start with the units in which the

original data were obtained. The mean diffusivities for the Wood Mountain clay loam of apparent density 1.28 are given in Figure 4. Note that this treatment of the results permits the inclusion of the vapour diffusion data at low moisture contents on the same plot with those for capillary conductivity. The curve is "J" shaped, indicating a minimum of movement in the region of the wilting percentage, with slightly higher values at lower moisture contents, and much higher values toward field capacity. The diffusivities below the wilting point are a little lower than those calculated using the known vapour pressure of the clay loam, and the diffusion coefficients predicted by Penman (12) or Van Bavel (20).

Neglecting gravity, the equation of flow is $\frac{\partial m}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial m}{\partial x}\right)$, and the problem is to find m, the moisture content, at different times t, and at different depths x, in the soil profile. The analytical solutions used in calculating heat conduction in the unsteady or transient state can not be applied to moisture movement because the diffusivity is a function of moisture content. Graphical or numerical methods must be used. Klute (10) developed an iterative method for solving the flow equation under certain boundary conditions. The procedure adapted in the present paper is somewhat the converse of that used in calculating the mean conductivities. The principles are those of the Schmidt graphical method (11), and the actual details follow the work of Dusinberre (4) who described the method for calculating heat losses from furnaces having walls with variable conductivities.

In order to compute moisture movement through a series of soil sections 1, 2, 3, etc., each of thickness Δ x, three main conditions must be met:

(i) A time interval Δ t must be chosen sufficiently small that the initial gradient between two adjoining sections can be used with negligible error to compute the moisture flow during the interval. For example, the flow between sections 1 and 2 would depend on $\frac{m_1 - m_2}{\Delta x}$.

(ii) The time interval Δ t must be sufficiently small so that the effect on any section of the moisture contents in any sections other than the adjoining ones can be neglected during the interval.

(iii) The depth of each section, Δ x, must be sufficiently small so that there is negligible error in taking the moisture content of its mid-point as the mean moisture for that section.

Assuming that these conditions obtain, the movement of moisture from section 1 to section 2 during the time interval, Δ t, may be represented by the equation:

$$\Delta x\,(m_2^1 - m_2) = \frac{(m_1 - m_2)}{\Delta x}\,D\,\Delta t$$

where m_2^1 is the moisture content at the middle of section 2 after time interval Δ t. According to condition (i) m_2^1 must not be greater than halfway between m_1 and m_2 during any interval, viz., $m\frac{1}{2} \leqslant \frac{1}{2}(m_1 + m_2)$. Then $m_2^1 - m_2 \leqslant \frac{1}{2}(m_1 - m_2)$, so that $\frac{D\,\Delta t}{(\Delta x)^2}$ must be $\leqslant \frac{1}{2}$ and $\Delta t \leqslant \frac{(\Delta x)^2}{2D}$.

According to this criterion, for the 0.5-inch sections used in these experiments, and with a diffusivity at 20 per cent moisture of approximately 0.6, the maximum time interval to be used in calculating is $\frac{(0.5)^2}{2 \times 0.6}$ or one-fifth day. In most field applications thicker sections, and hence longer time intervals could be used—for instance, for a 2-inch section at 20 per cent moisture a time interval of 2 to 3 days could be used, provided the moisture gradient was not changing rapidly with depth. An interval twice as long could be used at 17 per cent moisture.

The general procedure followed, starting with a given soil moisture profile at time t, is to calculate the moisture entering and leaving each section throughout the profile in successive time intervals Δ t. For example, if the moisture decreases with depth, and the moisture contents in sections 1 and 2 are known, the movement into section 2 can be calculated. Likewise, the movement from section 2 to section 3 can be calculated. By subtracting the latter from the former, one is able to find the net gain or loss in section 2 during the period. This procedure must be carried out for each section throughout the depth of soil concerned, and the moisture increments added to the original values to give the new moisture profile at time t + Δ t. Algebraically, $m_2^1 = m_2 + C_{12} + C_{32}$ when $C_{12} = \frac{(m_1 - m_2)}{(\Delta x)^2} D_{m12} \Delta t$ and $C_{32} = \frac{(m_3 - m_2)}{(\Delta x)^2} D_{m32} \Delta t$. In this way the gradual change

TABLE 1.—CONDUCTIVITY DATA USED FOR CORRECTION CHART

Soil moisture $m + 0.5$	Diffusivity D	$\sum_{1}^{m} 4D_{m+0.5}\Delta m$	Soil moisture $m + 0.5$	Diffusivity D	$\sum_{1}^{m} 4D_{m+0.5}\Delta m$
per cent	inch²/day		per cent	inch²/day	
1.5	0.25	1.0	14.5	0.15	5.6
2.5	0.22	1.9	15.5	0.18	6.3
3.5	0.18	2.6	16.5	0.22	7.2
4.5	0.12	3.1	17.5	0.30	8.4
5.5	0.10	3.5	18.5	0.40	10.0
6.5	0.05	3.7	19.5	0.52	12.1
7.5	0.03	3.8	20.5	0.70	14.9
8.5	0.02	3.9	21.5	0.90	18.5
9.5	0.02	4.0	22.5	1.15	23.1
10.5	0.03	4.1	23.5	1.50	29.1
11.5	0.05	4.3	24.5	1.92	36.8
12.5	0.08	4.6	25.5	2.38	46.3
13.5	0.10	5.0	26.5	2.90	57.9

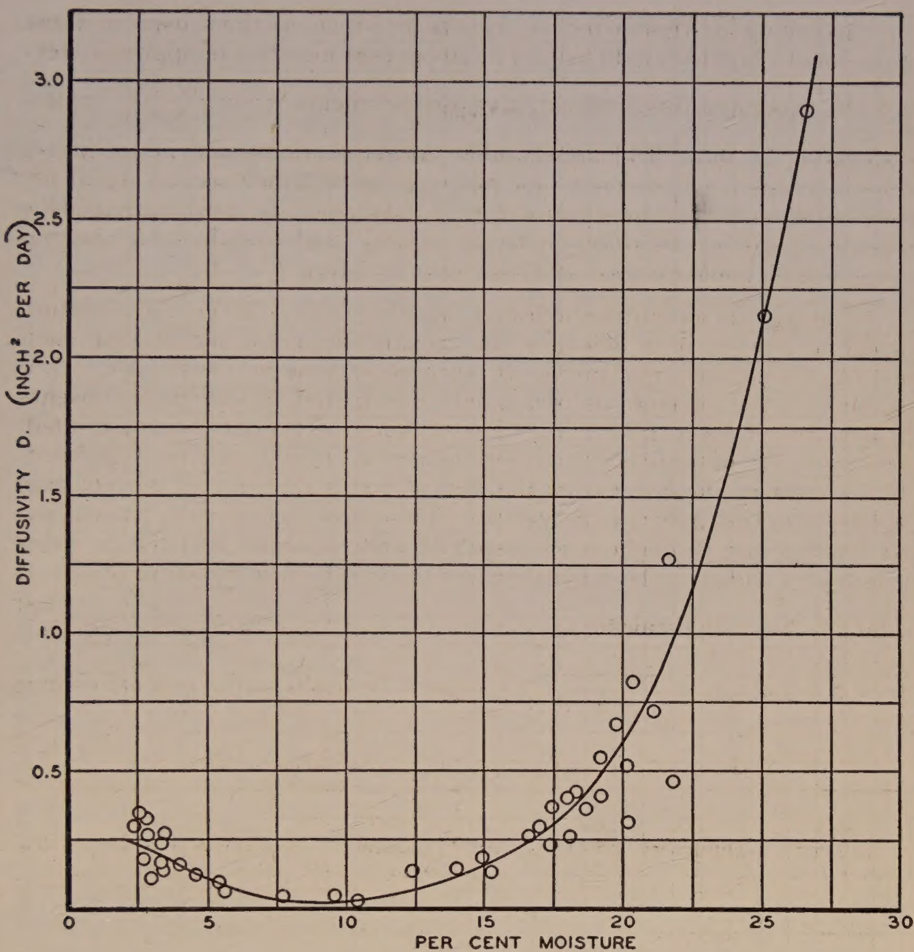

FIGURE 4. Diffusivity D for clay loam of apparent density 1.28.

can be computed for any period of time provided the diffusivity vs. moisture relationship remains unchanged, and the necessary boundary conditions are known.

Different mean values of D must be used for successive sections as the moisture content changes with depth. The diffusivity could be obtained by taking intercepts from the curve in Figure 4, but since this would be inaccurate and time-consuming, a correction chart is drawn up from which the mean diffusivity, or rather, the actual moisture movement for any gradient can be read off directly (Figure 5). The data and computation necessary for the chart are given in Table 1. Columns 2 and 5 are diffusivities taken from Figure 4 corresponding to different moisture contents. Columns 3 and 6 contain the summation of $\frac{D \Delta m}{(\Delta x)^2}$ computed for 1 to 26 per

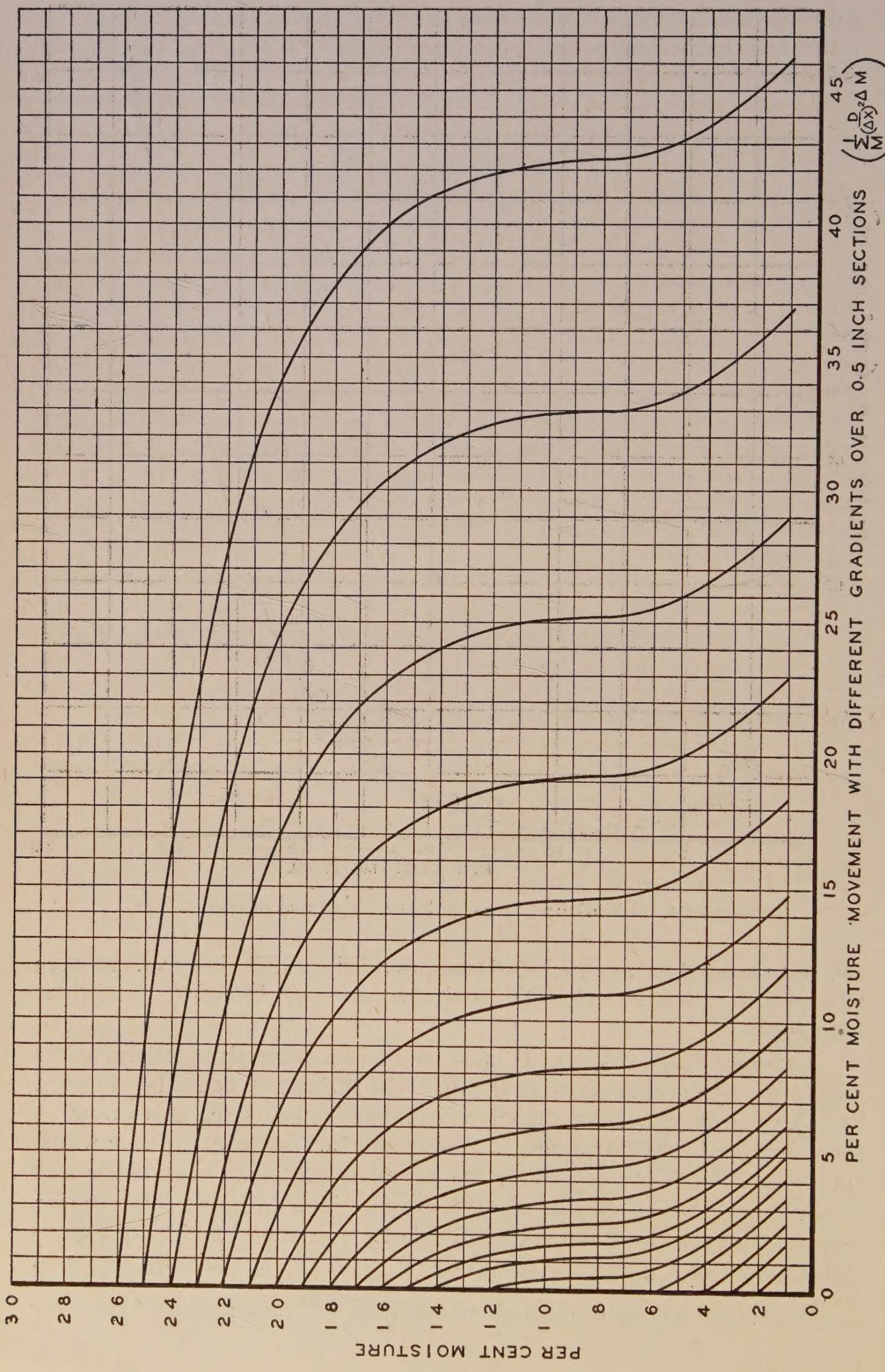

FIGURE 5. Correction chart for Wood Mountain clay loam, apparent density 1.28.

cent moisture, were Δ m is the moisture increment and Δ x is the depth of section. Actually, since the Δ m's are unity, and Δ x is 0.5 inch, the expression reduces to 4 times the sum of the D's.

As an example of the use of Table 1, suppose the moisture contents of two adjoining sections are 17 and 20 per cent, then the mean value of D is:

$$\overline{D} = \frac{D_{17.5} + D_{18.5} + D_{19.5}}{3}$$

The movement into the drier section is $C_{12} = \frac{(20 - 17)}{(\Delta x)^2}\overline{D}$ or simply

$4\,(D_{17.5} + D_{18.5} + D_{19.5})$ per cent moisture per day. Thus the difference between any two values in columns 3 or 6 of Table 1 gives the amount of moisture moving from one 0.5-inch section to the next under the gradient represented by the corresponding m values in columns 1 or 4.

The data from Table 1 are plotted in a special way in the correction chart, Figure 5, to give the moisture movement corresponding to different initial gradients. The sloping lines represent the moisture contents of moist sections of soil, and the horizontal lines those of adjoining drier sections. The moisture movement between any two such sections per day is given by the intercept made on the abscissa by a line falling vertically from the point where the lines representing the relevant moisture contents cross. The use of this chart is illustrated in Table 2 in which moisture movement is calculated for two intervals of the period 48 to 96 hours after water was added to loam soil. The measured moisture profile at 48 hours is given in the first row. The data in the second row are the amounts of moisture lost to the next lower section in each case. Row 3 contains the gains from the upper section. Rows 2 and 3 are then added and divided by 8 to give (in row 4) the change per section in Δ t = 3 hours, the approximate time interval set by the criterion described previously. Row 4 is then added to row 1 to give the new moisture profile at 51 hours. This procedure is repeated in successive Δ t's for any period of time required. The value of Δ t can be increased as the moisture content (and diffusivity) at the moist end of the profile decreases.

Figure 5 could be used for calculating the moisture movement for any preferred depth of section by changing the scale on the abscissa by means of the expression $\sum_{m}^{1} \frac{D}{(\Delta x)^2} \Delta m$, i.e., for a 1-inch section $(\Delta x)^2$ would be unity instead of 0.25 as at present, and the scale numbers would be divided by 4.

The force of gravity on downward movement was corrected for in plotting the data of Figure 4, but was omitted in the correction chart of Figure 5 and the calculations of Table 2. The effect is very small relative to the soil moisture gradient at moisture contents below field capacity. Gravity could be allowed for in Figure 5 by having the sloping lines branch into two, one above and one below the present lines, commencing at about 20 per cent moisture and spreading wider apart at higher moisture values. The upper line would be used to calculate movement downward and the

TABLE 2—SHEET FOR CALCULATING SOIL MOISTURE MOVEMENT.

Time	Section	1	2	3	4	5	6	7	8	9	10 etc. ⟶
48 hr.	Moisture %	22.7	22.2	21.5	20.5	18.8	16.5	9.7	3.3	2.5	2.5
	$C_{n+1,n}$	− 2.2	− 2.8	− 3.2	− 3.9	− 3.1	− 2.8	− 1.9	− 0.6	0	− 0.07
	$C_{n-1,n}$	—	+ 2.2	+ 2.8	+ 3.2	+ 3.9	+ 3.1	+ 2.8	+ 1.9	+ 0.6	0
	$\frac{\Sigma C}{8}$	− 0.28	− 0.08	− 0.05	− 0.09	+ 0.10	+ 0.04	+ 0.11	+ 0.16	+ 0.08	− 0.01
51 hr.	—	22.42	22.12	21.45	20.41	18.90	16.54	9.81	3.46	2.58	2.49
92 hr.	—	20.96	20.78	20.15	19.68	18.48	16.59	12.15	4.67	3.35	2.84
	$C_{n+1,n}$	− 0.5	− 1.7	− 1.2	− 2.2	− 2.5	− 2.5	− 1.4	− 0.7	− 0.4	− 0.2
	$C_{n-1,n}$	—	+ 0.5	+ 1.7	+ 1.2	+ 2.2	+ 2.5	+ 2.5	+ 1.4	+ 0.7	+ 0.4
	$\frac{\Sigma C}{6}$	− 0.08	− 0.20	+ 0.08	− 0.17	− 0.05	0	+ 0.18	+ 0.12	+ 0.05	− 0.03
96 hr., calculated	—	20.88	20.58	20.23	19.51	18.43	16.59	12.33	4.79	3.40	2.87
96 hr., measured	—	21.2	20.7	20.2	19.5	18.2	16.6	13.4	4.5	3.2	2.8

lower line movement upward. This type of branched chart could not be used for values of Δ x other than the one for which the gravity corrections were estimated.

The procedure of Table 2 can be used equally well for upward movement or evaporation from a soil surface. For the latter, the relationship between moisture loss under given evaporating conditions of the atmosphere and the moisture content of the top section of soil is necessary. The loss during the time interval Δ t must be entered in the appropriate column of the table at each stage of the computation.

The data and methods described in the present paper are intended to supplement and extend field observations. It would be difficult to obtain accurate conductivity data by sampling field soils at frequent intervals. On the other hand, soil moisture profiles are obtained at longer periods of a few weeks or months in connection with various projects. Commencing with approximate diffusivities, it should be possible to estimate the movement for the measured periods, and if necessary, to adjust the diffusivities to fit field conditions by successive approximations. Applications of immediate interest to the Soil Research Laboratory concern losses of stored moisture from summer fallowed fields by movement below the root zone and by surface evaporation.

REFERENCES

1. Bodman, G. B., and E. A. Colman. Moisture and energy conditions during downward entry of water into soils. Soil Sci. Soc. Amer. Proc. 8 : 116-122. 1944.
2. Bouyoucos, G. J. Effect of temperature on the movement of water vapour and capillary moisture in soils. J. Agr. Res. 5 : 141-172. 1915.
3. Childs, E. C., and N. Collis-George. Permeability of porous materials. Proc. Roy. Soc. 201A : 392-405. 1950.
4. Dusinberre, G. M. Numerical methods for transient heat flow. Trans. Amer. Soc. Mech. Eng. 67 : 703-712. 1945.
5. Gardner, W. A capillary transmission constant and methods of determining it experimentally. Soil Sci. 10 : 103-126. 1920.
6. Gardner, W., and J. A. Widtsoe. The movement of soil moisture. Soil Sci. 11 : 215-232. 1921.
7. Gardner, W. H., and W. Gardner. Movement of soil moisture in the unsaturated state. Soil Sci. Soc. Amer. Proc. 15 : 42-50. 1950.
8. Gurr, C. G., T. J. Marshall, and J. T. Hutton. Movement of water in soil due to a temperature gradient. Soil Sci. 74 : 335-345. 1952.
9. Jones, H. E., and H. Kohnke. Influence of soil moisture tension on vapour movement of soil water. Soil Sci. Soc. Amer. Proc. 16 : 245-248. 1952.
10. Klute, A. A numerical method for solving the flow equation for water in unsaturated materials. Soil Sci. 73 : 105-116. 1952.
11. McAdams, W. H. Heat transmission. 2nd ed. McGraw-Hill, Inc., New York. 1942.
12. Penman, H. L. Gas and vapour movements in the soil. I. The diffusion of vapours through porous solids. J. Agr. Sci. 30 : 437-462. 1940. II. The diffusion of carbon dioxide through porous solids. J. Agr. Sci. 30 : 570-581. 1940.
13. Richards, L. A. Capillary conductivity data for three soils. J. Amer. Soc. Agron. 28 : 297-300. 1936.
14. Richards, L. A., and B. D. Wilson. Capillary conductivity measurements in peat soils. J. Amer. Soc. Agron. 28 : 427-431. 1936.
15. Richards, L. A. Pressure membrane apparatus, construction and use. Agr. Eng .28 : 451-454, 460. 1947.

16. Richards, L. A. Porous plate apparatus for measuring moisture retention and transmission by soil. Soil Sci. 66 : 105-110. 1948.
17. Richards, L. A., and D. C. Moore. Influence of capillary conductivity and depth of wetting on moisture retention in soil. Amer. Geophys. Union Trans. 33 : 531-540. 1952.
18. Smith, F. B., and P. E. Brown. The diffusion of carbon dioxide through soils. Soil Sci. 35 : 413-423. 1933.
19. Taylor, S. A. Oxygen diffusion in porous media as a measure of soil aeration. Soil Sci. Soc. Amer. Proc. 14 : 55-61. 1950.
20. Van Bavel, C. H. M. Gaseous diffusion and porosity in porous media. Soil Sci. 73 : 91-104. 1952.

ANTIBIOTIC FEED SUPPLEMENTS IN WESTERN CANADIAN SWINE RATION[1]

R. Hironaka[2] and J. P. Bowland[3]

University of Alberta, Edmonton, Alta.

[Received for publication November 9, 1953]

ABSTRACT

In experiments conducted to study the effects of the addition of antibiotic feed supplements to typical western Canadian rations for bacon hogs, the rate of gain was generally increased by aureomycin or penicillin supplementation of the ration. The increase was not significant in all cases and there was a wide variability in response of pigs to the antibiotic supplements. No definite protein-sparing effect was found when an antibiotic was added to the ration, and there was actually some indication of an increased protein requirement.

When an antibiotic supplement was fed to 200 lb. liveweight, there was frequently a trend toward reduction in carcass quality and lower Advanced Registry scores. When the antibiotic supplements were discontinued when the pigs weighed 75 or 125 lb., carcass quality was not affected.

There was a greater shrinkage from hot to cold carcass weight in carcasses from pigs fed antibiotics than in those from pigs not receiving any antibiotic supplement.

INTRODUCTION

The addition of antibiotic feed supplements to rations intended for growing and finishing swine is becoming an increasingly common practice in Canada. Up to the present there is insufficient factual information on the advisability of using these supplements in the production of bacon hogs.

Several investigators (4, 7, 10, 14) have reported that the feeding of antibiotics to pigs results in improved rates of gain (i.e. mean daily gain in live weight), but this is not an unanimous observation (15, 16). There is some indication that antibiotic supplements in the ration will reduce the level of dietary protein required to permit pigs to attain a standard rate of gain. For example, Cunha (9) concluded that when aureomycin supplement was added to a corn-peanut meal ration, the protein content could be reduced by 10 per cent without depressing the pigs' rate of growth. Similar observations were made by Catron *et al.* (8) for rations containing aureomycin, and by Hoefer *et al.* (12) for rations containing 5 mg. of terramycin per pound of feed. It has been suggested (12) that these results indicate that antibiotics improve the utilization of protein, or have a 'protein-sparing' effect. Adequate nitrogen retention data to support this conclusion have yet to be obtained in connection with pigs.

Under Canadian standards, an accurate measurement of carcass quality may be obtained by the use of Advanced Registry measurements and scores. A trend toward lower Advanced Registry scores of carcasses from pigs receiving aureomycin supplement to market weight was reported by Bowland *et al.* (4). Antibiotic supplements in rations have the apparent effect of reducing carcass length (4), and of increasing fat depth over the back and loin of the pig (2, 4). The effect of antibiotic supplements on carcass quality in swine is a controversial subject. For example, Catron

[1] Contributed by Department of Animal Science, University of Alberta, Edmonton, Alta.
[2] Lecturer in Animal Husbandry.
[3] Associate Professor of Animal Husbandry.

TABLE 1.—BASAL RATION, EXPERIMENT 1

——	Period 1, 40-125 lb.	Period 2, 125-200 lb.
	%	%
Barley (12.9 per cent protein)	63	58
Oats (11.1 per cent protein)	25	36
Protein-mineral supplement*	12	6

* The supplement (34.1 per cent protein) fed was as follows:

Soybean oil meal	50
Linseed oil meal	25
Alfalfa meal	15
Limestone	5
Salt (iodized)	5

et al. (8), using lard type hogs, observed no significant differences between antibiotic and non-antibiotic treatments in respect to back fat depth, length and depth of body or per cent of lean in the carcass. Of interest in this respect was the conclusion (11) that the addition of terramycin to the diet of rats increases carcass dry matter gains, mainly by enhancing fat deposition.

EXPERIMENTAL

Much of the work on antibiotic supplementation of feeds has been done using the lard type pig, and it is evident that more complete studies should be made with the bacon hog under Canadian conditions of feeding and management. This paper reports some observations on the comparative value of aureomycin and penicillin supplements; on the effect of feeding antibiotic supplements for a limited time or until the pigs reach market weight; and on the interaction between antibiotic and protein content of the ration.

The antibiotic supplements used contained (1) procaine penicillin or (2) aureomycin hydrochloride†.

Purebred Yorkshire weanling pigs from the University herd were divided at the time of allotment on the basis of weight, sex and ancestry. All experiments were conducted using group feeding in drylot, with the pigs being self-fed and supplied with water ad libitum. The pigs were marketed when they reached a liveweight of 200 ± 10 pounds.

Experiment 1

The object of this first experiment was to study the effect on carcass quality, rate of gain and efficiency of feed utilization in pigs when antibiotic supplements were added to the ration for a limited time or until the pigs reached market weight. Basal ration 1, shown in Table 1, was fed during the growing period until the pigs of each lot reached an average weight of 125 lb., and ration 2 was fed during the finishing or fattening period from 125 to 200 lb. in weight.

† Penicillin supplement containing 12.5 mg. vitamin B_{12} and 2 gm. procaine penicillin per pound was supplied through the courtesy of Merck and Co., Ltd., Montreal, Que. Aureomycin supplement (Aurofac) containing 1.8 mg. vitamin B_{12} and 1.8 gm. aureomycin hydrochloride per pound was supplied through courtesy of Lederle Laboratories, Pearl River, N.Y.

The aureomycin supplement was added at a level of 0.5 per cent of the ration and supplied 9 mg. of aureomycin hydrochloride per lb. of ration. The penicillin supplement was added at a level of 0.05 per cent of the ration and supplied 1 mg. of procaine penicillin per lb. of ration. The levels used were those recommended at that time by the manufacturers of the two supplements. In earlier trials at the University of Alberta, these levels of aureomycin and penicillin supplements have resulted in similar rates of gain in pigs.

Adequate supplemental vitamins A and D were fed daily until a weight of 125 lb. was reached. Earlier work at the University of Alberta has indicated no need of supplemental vitamins A and D in market hog rations during the finishing period.

The groups, consisting of 6 pigs each, were supplemented as follows:

Lot 1—Basal ration.
Lot 2—Basal ration plus aureomycin supplement to 75 lb.
Lot 3—Basal ration plus aureomycin supplement to 125 lb.
Lot 4—Basal ration plus aureomycin supplement to 200 lb.
Lot 5—Basal ration plus penicillin supplement to 75 lb.
Lot 6—Basal ration plus penicillin supplement to 125 lb.
Lot 7—Basal ration plus penicillin supplement to 200 lb.

Experiment 2

The object of this experiment, in which replicate trials were conducted during two separate seasons, was to study carcass quality, rate of gain and feed efficiency in swine as affected by rations containing various levels of protein with or without antibiotics.

As shown in Table 2, the pigs in both trials were fed rations containing 17, 15 or 13 per cent crude protein until an average weight of 110 lb. was reached. In addition, one lot of pigs receiving each of the three levels of protein received a penicillin feed supplement. The antibiotic supplement was fed as 0.1 per cent of the ration to supply procaine penicillin at a level of 2 mg. per pound of feed. From 110 to 200 lb. in weight, all pigs received

TABLE 2.—RATIONS FED IN EXPERIMENT 2

Lot No.	Crude protein	Antibiotic supplement	Trial A		Trial B	
			Grain	Protein supplement	Grain	Protein supplement
	%					
1	17	None	81.0	18.0	81.9	17.1
2	17	0.1%	81.0	18.0	81.9	17.1
3	15	None	87.7	11.3	89.1	9.9
4	15	0.1%	87.7	11.3	89.1	9.9
5	13	None	94.3	4.7	96.4	2.6
6	13	0.1%	94.3	4.7	96.4	2.6

TABLE 3.—RATES OF GAIN, FEED EFFICIENCIES AND CARCASS MEASUREMENTS AND SCORES

Ration		Lot No. 1	2	3	4	5	6	7
		Basal	Aureomycin supplement to 75 lb.	125 lb.	200 lb.	Penicillin supplement to 75 lb.	125 lb.	200 lb.
Number of pigs		6	6	6	6	6	6	6
Initial to 75 lb.:								
Av. daily gain	lb.	1.08	1.20	1.32	1.35	0.96	1.08	1.14
Av. daily feed	lb.	3.64	3.75	3.81	3.94	3.26	3.40	3.48
Feed/100 lb. gain	lb.	342	312	290	293	341	313	306
Initial to 125 lb.:								
Av. daily gain	lb.	1.22	1.23	1.43	1.46	1.17	1.23	1.41
Av. daily feed	lb.	4.24	4.37	4.86	4.74	4.12	4.29	4.39
Feed/100 lb. gain	lb.	354	357	340	325	353	350	311
Initial to 200 lb.:								
Av. number of days on trial		123	120	109	104	125	126	117
Av. daily gain	lb.	1.31	1.34	1.48	1.55	1.28	1.28	1.41
Av. daily feed	lb.	4.96	5.13	5.56	5.79	4.88	4.96	5.34
Feed/100 lb. gain	lb.	381	383	376	373	380	387	379
Shrinkage (hot to cold carcass weight)	%	2.53	3.41	3.67	3.73	3.22	3.36	2.96
Length of side	in.	30.9	30.8	31.0	30.6	30.7	30.9	30.3
Thickness of fat:								
Shoulder	in.	1.94	2.10	2.00	2.08	1.98	1.93	2.03
Back	in.	1.08	1.10	1.08	1.10	1.05	1.03	1.12
Loin	in.	1.46	1.53	1.50	1.48	1.42	1.40	1.47
Area of loin	sq. in.	3.55	3.54	3.49	3.23	3.48	3.59	3.50
Total A.R. score		73	69	70	61	70	76	64

a ration containing 13 per cent protein without antibiotic supplement as was fed to the pigs in lot 5 during the growing period. The protein supplement was formulated to contain 35 per cent meat scraps, 25 per cent soybean oil meal, 25 per cent linseed oil meal and 15 per cent dehydrated alfalfa meal. The ratio of barley to oats in all rations during the entire growing and finishing period remained constant at 2 : 1. The rations contained 1 per cent mineral made up of equal parts of limestone and iodized salt.

RESULTS AND DISCUSSION

Experiment 1

A summary of rates of gain, feed efficiencies and carcass measurements is given in Table 3.

In the period up to an average weight of 75 lb. pigs receiving aureomycin supplement (lots 2, 3 and 4) gained significantly faster ($p=0.01$)* compared to the control group (lot 1) or the pigs receiving penicillin supplement (lots 5, 6 and 7). However, at an average weight of 125 lb., or 200 lb., no significant differences were found even though pigs receiving antibiotic supplement, particularly aureomycin supplement, did appear to gain at a faster rate. Although both supplements contained vitamin B_{12}, any effect of the supplements can probably be attributed to the antibiotic present, as earlier work by Bowland *et al.* (4) indicated that vitamin B_{12} supplements had no appreciable effect when added to similar swine rations.

Removal of the antibiotic supplement from the ration when an average weight of 75 lb. was attained by the pigs did not appear to cause any marked depression in rate of gain. However, when the antibiotics were fed to 125 lb. in weight, and then removed from the ration, there was a period of up to two weeks when rate of gain was sharply reduced. Following this period, the pigs continued to gain weight at a normal rate. Bird (3) reported similar findings with chicks fed 40 mg. of streptomycin per kg. of feed.

While some apparent improvement in feed efficiency (feed required to produce 100 pounds of liveweight gain) in pigs from antibiotic-supplemented lots was observed during the earlier stages of the trial, in the overall experiment the feed efficiency was almost identical from one lot to another.

A trend toward a reduction in length of side (measured from the outside of the first rib to the inner edge of the aitch bone) and lower total Advanced Registry score appeared to result when the antibiotic supplements were fed to market weight, although the differences were not statistically significant. The apparent reduction in total score from 73 in the control lot to 61 and 64 in the lots receiving antibiotic to 200 lb. in weight was similar to results reported by Bowland *et al.* (4). Feeding of the antibiotic supplements to 75 or 125 lb. did not affect carcass grades or Advanced Registry measurements or scores.

Carcasses from pigs which received an antibiotic supplement either for a limited period or to market weight shrank an average of 5.1 lb. on cooling for approximately 48 hours, while the carcasses of pigs which did not receive

*Analysis of variance. Johnson (13).

TABLE 4.—RATES OF GAIN AND FEED EFFICIENCIES, EXPERIMENT 2

		Lot No.					
		1	2	3	4	5	6
Ration		17 per cent protein		15 per cent protein		13 per cent protein	
Antibiotic		−	+	−	+	−	+
Trial A—							
Number of pigs		6	6	6	6	6	6
Initial to 110 lb.:							
Av. daily gain	lb.	1.11	1.23	1.00	1.19	0.89	1.13
Av. daily feed	lb.	3.83	3.80	3.85	3.78	3.87	4.25
Feed/100 lb: gain	lb.	346	329	385	316	433	377
Initial to 200 lb.:							
Av. number of days on trial		139	125	146	128	154	135
Av. daily gain	lb.	1.20	1.41	1.15	1.31	1.10	1.25
Av. daily feed	lb.	5:06	5.33	5.33	5.16	5.17	5.70
Feed/100 lb. gain	lb.	422	397	465	393	472	454
Trial B—							
Number of pigs		5	5	5	5	5	5
Initial to 110 lb.:							
Av. daily gain	lb.	1.23	1.32	1.07	1.07	0.99	1.09
Av. daily feed	lb.	3.82	4.59	4.67	3.98	4.45	3.06
Feed/100 lb. gain	lb.	312	348	437	371	452	363
Initial to 200 lb.:							
Av. number of days on trial		118	106	122	122	120	125
Av. daily gain	lb.	1.39	1.55	1.34	1.20	1.29	1.25
Av. daily feed	lb.	5.08	6.00	6.06	4.73	5.24	5.10
Feed/100 lb. gain	lb.	365	386	451	395	405	408

an antibiotic supplement shrank an average of only 3.8 pounds. This difference in shrinkage was significant ($p=0.05$) and indicates that the carcasses from pigs fed antibiotic probably contained more water. Increased water consumption by pigs receiving antibiotic supplement has been reported by Card (5), and observed in unreported work at the University of Alberta.

Experiment 2

A summary of rates of gain and feed efficiencies for the pigs in the two trials is presented in Table 4, while a summary of Advanced Registry carcass measurements and scores is presented in Table 5.

As summarized in Table 4, the rate of gain made by pigs in trial A receiving penicillin supplement (lots 2, 4 and 6) was significantly ($p=0.01$) higher than that of the pigs on the basal rations. This advantage in rate of gain was maintained even after the antibiotic was removed from the ration. The data could be interpreted to indicate that a "protein sparing" effect occurred when penicillin supplement was added to the ration, as pigs receiving 13 per cent protein and antibiotic grew as rapidly as those receiving 17 per cent protein without antibiotic. However, it would appear that the optimum level of protein may not yet have been reached as faster gains appeared to be obtained as protein levels in the ration were increased. This would tend to bear out the suggestion of Almquist (1) that antibiotic supplements actually increase protein requirements. On this basis, to obtain optimum benefits from antibiotic supplements in the ration, the level of protein must be maintained or even increased above what is necessary for optimum growth without antibiotic supplements.

While there was an apparent trend toward a slower rate of gain as the level of protein in the ration was lowered, the differences were not statistically significant. Feed efficiencies were not altered appreciably by the addition of antibiotic supplements to the ration. As protein was reduced in the ration, pounds of feed per 100 pounds gain tended to increase.

In trial B, neither penicillin supplement nor the level of protein in the ration affected the rate of gain significantly. As in trial A, there appeared to be a trend toward slower rate of gain as the level of protein in the ration was reduced. Feed required by the pigs to make 100 pounds of liveweight gain did not appear to be affected by antibiotic supplementation or by variation in protein level of the ration. When the antibiotic supplement was removed from the rations in the finishing period, there was a very definite reduction in rate of gain of pigs formerly receiving antibiotic supplement compared to that of pigs which had never received any antibiotic supplement. This reduction was pronounced in lots 4 and 6 which during the growing period received 15 and 13 per cent protein respectively, while in lot 2 which had received 17 per cent protein little slowing of rate of growth occurred. There is an indication in this observation that removal of antibiotic supplements from rations in the finishing period may sometimes reduce the rate of gain below that of pigs which have never received an antibiotic supplement. Burnside *et al.* (5) reported that deletion of antibiotic from the ration during the middle or latter part of the feeding period caused a concomitant decrease in rate of gain.

TABLE 5.—CARCASS MEASUREMENTS AND SCORES

		Lot No.					
		1	2	3	4	5	6
Protein during growing period, per cent		17	17	15	15	13	13
Antibiotic supplement		−	+	−	+	−	+
Trial A—							
Shrinkage	%	3.17	3.54	3.21	4.14	3.07	3.49
Length of side	in.	31.2	30.8	31.1	30.5	30.7	31.2
Thickness of fat:							
Shoulder	in.	1.92	2.00	1.85	1.98	2.08	2.03
Back	in.	0.90	1.05	0.92	1.00	1.02	1.03
Loin	in.	1.32	1.48	1.33	1.43	1.43	1.50
Area of loin	sq. in.	3.48	3.17	3.48	3.20	3.62	3.17
Total A.R. score		78	64	81	70	70	66
Trial B—							
Shrinkage	%	2.66	3.31	3.05	3.31	2.45	2.75
Length of side	in.	30.8	31.3	31.0	30.9	30.4	30.4
Thickness of fat:							
Shoulder	in.	1.86	1.98	2.18	1.98	2.00	1.84
Back	in.	0.96	0.96	1.14	1.08	1.00	0.98
Loin	in.	1.34	1.48	1.58	1.48	1.56	1.40
Area of loin	sq. in.	3.46	3.29	3.50	3.41	3.17	3.19
Total A.R. score		79	72	66	75	64	71

The data in Table 5 indicate that in trial A the shrinkage in carcass weight during cooling for approximately 48 hours, and the thickness of loin fat and back fat of carcasses of pigs were significantly increased ($p=0.05$) in lots where antibiotic supplement was fed compared to carcasses from pigs which did not receive antibiotic supplement. In addition, the area of loin (area of the cross-section of the main back muscle or "eye of lean" taken when the carcass is cut at the last rib) of the carcasses from pigs receiving antibiotic supplement was reduced to a highly significant extent ($p=0.01$). Total Advanced Registry scores appeared to be reduced in all lots where antibiotic was fed, but there were no statistically significant differences. Interactions (protein $\times$ antibiotic) were not significant. In trial B, a replicate of trial A, none of the Advanced Registry carcass measurements or scores was affected to a significant extent by the addition of penicillin supplement to the ration. There was a trend toward increased shrinkage during cooling of the carcasses from antibiotic supplemented hogs, but the differences in this trial were not statistically significant as they were in previous experiments.

The difference in the effect of antibiotic feed supplements on carcass measurements between trials A and B may be a reflection of the difference in rate of gain of the pigs in the two trials. The average daily gain was not affected significantly by antibiotic supplementation of the ration in trial B, whereas in trial A there was a significant increase in rate of gain attributable to the addition of antibiotic to the ration. Differences in type of hog may also help to explain differences in results in carcass data as influenced by antibiotic supplements.

In conclusion, these experiments have indicated that aureomycin supplement, and to a lesser extent penicillin supplement, will often increase the rate of liveweight gain in swine. If the antibiotic feed supplements were fed to market weight, carcass quality was reduced in some cases by increased fat deposition over the shoulder, loin and back, by reduction in length of the carcasses, and by reduced area of loin. This reduction in quality of carcasses was not apparent if antibiotic supplements were removed from the ration by the time that the pigs were 125 lb. in weight. There was a trend in some cases for a sudden reduction in rate of gain after the antibiotic supplement was removed from the ration. Increased shrinkage on cooling for approximately 48 hours after slaughter occurred in the carcasses from pigs which had received an antibiotic supplement as compared to those which had received no supplement.

ACKNOWLEDGMENT

This work was supported in part by a grant from the Prairie Regional Laboratory of the National Research Council. The authors wish to express their appreciation to the Production Service, Canada Department of Agriculture, for cutting and scoring the pigs in these experiments by Advanced Registry standards.

REFERENCES

1. Almquist, H. J. Amino acid requirements of chickens and turkeys—Review. Poult. Sci. 31 : 966. 1952.
2. Beeson, W. M. Role of antibiotics in swine feed. Flour and Feed 53 : 16. 1952.
3. Bird, H. R. Antibiotics in feed. Feedstuffs 32 : 10. 1950.
4. Bowland, J. P., S. E. Beacom, and L. W. McElroy. Animal protein factor and antibiotic supplementation of small grain rations for swine. J. Anim. Sci. 10 : 629. 1951.
5. Burnside, J. E., R. H. Grummer, P. H. Phillips and G. Bohstedt. The effect of intermittent administration of aureomycin to growing-fattening swine. J. Anim. Sci. 12 : 828. 1953.
6. Card, L. E. Feedstuffs 23 : 1. 1951.
7. Carpenter, L. E. Effect of aureomycin on the growth of weaned pigs. Arch. Biochem. 27 : 469. 1950.
8. Catron, D. V., A. H. Jensen, P. G. Homeyer, H. M. Maddock, and G. C. Ashton. Re-evaluation of protein requirements of growing fattening swine as influenced by feeding an antibiotic. J. Anim. Sci. 11 : 221. 1952.
9. Cunha, T. J. Latest developments on APF, B_{12}, aureomycin and related factors for the growing pig. Nutr. Conf., Tex. Agr. and Mech. Coll. 1950.
10. Edwards, H. M., T. J. Cunha, G. B. Meadows, R. F. Sewe, and C. B. Shawver. Observations on aureomycin and APF for the pig. Proc. Soc. Exp. Biol. Med. 75 : 445. 1950.
11. Hartsook, E. W., and B. C. Johnson. Effects of dietary terramycin and methionine supplements on fat and protein gains in weanling rats. J. Nutrition 51 : 205. 1953.
12. Hoefer, J. A., R. W. Luecke, F. Thorp, Jr., and R. L. Johnston. The effect of terramycin on the growth of pigs fed different levels of protein. J. Anim. Sci. 11 : 455. 1952.
13. Johnson, L. P. V. An introduction to applied biometrics. Burgess Pub. Co., Minneapolis 15, Minn. 1950.
14. Jukes, T. H., E. L. R. Stokstad, R. R. Taylor, T. J. Cunha, H. M. Edwards, and G. B. Meadows. Growth promoting effect of aureomycin on pigs. Arch. Biochem. 26 : 324. 1950.
15. Sheffy, R. B., R. H. Grummer, P. H. Phillips, and G. Bohstedt. Comparison of growth responses of 2-day-old pigs to streptomycin, aureomycin and crude APF alone and in combination with B_{12}. J. Anim. Sci. 11 : 97. 1952.
16. Speer, V. C., R. L. Vohs, D. B. Catron, H. M. Maddock, and C. C. Culbertson. Effect of aureomycin and animal protein factor on healthy pigs. Arch. Biochem. 29 : 452. 1950.

THE EFFECT OF NITROGEN ADDITIONS ON FERTILIZER PHOSPHATE AVAILABILITY[1]

D. A. Rennie and J. Mitchell[2]

University of Saskatchewan, Saskatoon, Sask.

[Received for publication November 30, 1953]

ABSTRACT

The greater availability of ammonium phosphates over mono-calcium phosphates in high base status soils could be due to the nutritional value of its nitrogen content, to its greater water solubility, to a slower rate of fixation or to a combination of these factors. The experiments reported here were designed to answer these questions by comparing equal rates of radiophosphate carriers, the carriers being ammonium phosphate and T.S.P., to which varying amounts of ammonium nitrate were added.

On fallow, there was no indication of any significant increase in yield due to the nitrogen addition, even when NH_4NO_3 was added in relatively large amounts (30 pounds N per acre). Thus, it seems unlikely that the nutritive value of the nitrogen is responsible for the superiority of ammonium phosphate (11-48-0) over other phosphate fertilizers in this region.

Marked increases in the uptake of fertilizer phosphate from both carriers (11-48-0 and T.S.P.) occurred as the amount of added nitrogen was increased. If, for example, sufficient nitrogen is added to T.S.P., the uptake of phosphorus from this basic fertilizer can be enhanced to a point where it exceeds that of the highly available 11-48-0. A lowering of the pH in the vicinity of the fertilizer due to the addition of an acid-forming product such as NH_4NO_3 was suggested as a reason for this marked increase in availability. The ammonium ion content of the ammonium phosphate carrier would similarly increase the availability in high base status soils.

Stubble trash reduced fertilizer availability considerably. This reduction in availability was partially overcome by the addition of nitrogen to the carriers.

INTRODUCTION

Fertilizer trials conducted over a number of years on diverse Saskatchewan soils have indicated that ammonium phosphate (11-48-0) is a more efficient phosphate carrier than calcium phosphates such as superphosphate or triple superphosphate (T.S.P.) (9). This general superiority of ammonium phosphate fertilizers has been shown to be correlated with their ability to supply greater amounts of phosphate to the growing plant (2, 3, 10).

The reason for the greater availability of the phosphate in the ammonium phosphate form could be due to the nutritional value of the nitrogen in the carrier. This can be partially discounted since field strip fertilizer tests on fallow land have not shown general yield increases due to the addition of nitrogen to 11-48-0 (4). However, on stubble land, particularly where a heavy trash cover remained from the previous crop, additional nitrogen has resulted in significant yield response (5).

The greater efficiency of ammonium phosphate over other phosphate carriers could also be due to its chemical characteristics, such as its greater solubility, or possibly because of a slower rate of fixation in high base status soils. Undoubtedly, these characteristics are reflected in the ability of ammonium phosphate fertilizer to supply a maximum amount of available phosphorus during the initial growth period when the plant is absorbing the greatest portion of its fertilizer phosphorus (13).

---

[1] Contribution from the Department of Soil Science, University of Saskatchewan, Saskatoon, Sask. Presented by the senior author before the Soils Section, Agricultural Institute of Canada, Saskatoon, June, 1953.

[2] Assistant Professor and Professor of Soil Science, respectively.

The experiments reported here were designed to answer these questions by comparing equal rates of radioactive phosphate carriers, the carriers being mono-ammonium phosphate and mono-calcium phosphate to which varying amounts of NH_4NO_3 were added. Preliminary field tests were carried out in 1951 and constituted plots located in the Brown, Dark Brown, Black and Grey Soil Zones. These were repeated and their scope enlarged in 1952. The latter season's work included 10 field plots. The individual plot sites were selected to cover a range of soil and climatic conditions. Soil samples were taken in the vicinity of the plots and routine laboratory tests, including pH, soluble salts, available phosphate, total nitrogen, and organic and inorganic carbon were conducted. These data, together with descriptions of soil types, are listed in Table 1.

MATERIALS AND METHODS

The field plots were arranged in a randomized block design using six replicates. The fertilizer and seed were applied at a uniform depth using a specially constructed power seeder. Each treatment consisted of a central row fertilized with radioactive fertilizer and two adjacent guard rows which were given the same fertilizer treatment using inactive fertilizer.

The active and inactive ammonium phosphate and T.S.P. were obtained from the Plant Industry Branch, United States Department of Agriculture, Beltsville, Md. The specific activity of the tagged fertilizers was approximately 100 μc P^{32} per gram P^{31} at seeding time. Thatcher wheat was grown as the test crop. Identical fallow trials were placed at each location in 1951 and constituted the following treatments:

(1) Control—no fertilizer.
(2) Mono-ammonium phosphate (11-48-0).
(3) Mono-calcium phosphate (T.S.P.).
(4) T.S.P. plus 5.5 lb. N as NH_4NO_3.

Both phosphate carriers were applied at a uniform rate of 24 lb. P_2O_5 per acre. It is to be noted that the treatments T.S.P. plus 5.5 lb. N and 11-48-0 contain equivalent amounts of both N and P.

In 1952, six smaller trials were set out at scattered locations on fallow and identical treatments to those followed in 1951 were used. In addition, four larger trials were set out on adjacent summerfallow and stubble land at Watson, on Yorkton Loam, and at Birch Hills on Melfort Silty Clay Loam. The eight treatments compared were:

(1) Control—no fertilizer.
(2) T.S.P.
(3) T.S.P. plus 5.5 lb. N as NH_4NO_3.
(4) 11-48-0.
(5) T.S.P. plus 30 lb. N as NH_4NO_3.
(6) 11-48-0 plus 24.5 lb. N as NH_4NO_3.
(7) T.S.P. plus 30 lb. N as NH_4NO_3 applied as a top dressing at the four-leaf stage.
(8) 11-48-0 plus 24.5 lb. N applied as a top dressing at the four-leaf stage.

TABLE 1.—ANALYSIS OF REPRESENTATIVE SURFACE SAMPLES TAKEN IN THE VICINITY OF THE FIELD PLOTS

Location	Soil, type and description[1]	Soluble salts (cond. mmhos)[2]	pH	p.p.m. avail. P[3]	Per cent N	Per cent O.M.[4]	Per cent inorganic carbonates
Kyle	*Sceptre heavy clay*—Brown soil developed on heavy glacial lacustrine deposits	0.87	6.6	14.5	0.27	5.1	—
Rosetown	*Regina heavy clay*—Dark brown soil developed on heavy glacial lacustrine deposits	0.54	7.9	10.0	—	—	1.25
Melfort	*Melfort silty clay*—Thick black soil developed on heavy glacial lacustrine deposits	0.83	5.9	26.0	0.57	11.3	0.42
Birch Hills	*Melfort silty clay loam*—Thick black soil developed on heavy glacial lacustrine deposits	0.52	6.3	18.0	0.56	11.0	0.30
Birsay	*Haverhill loam*—Brown soil developed on glacial till	1.25	6.2	17.0	0.24	4.8	0.17
Hawarden	*Weyburn clay loam*—Dark brown soil developed on glacial till	1.08	6.5	24.0	0.31	5.6	0.17
Harris	*Asquith fine sandy loam*—Dark brown soil developed on sandy alluvial deposits	0.75	6.3	18.0	0.17	3.2	0.17
Watson	*Yorkton loam*—Calcareous thick black soil developed on resorted till	0.86	7.7	20.0	0.35	7.6	2.25
Northside	*Waitville loam*—Gray wooded soil developed on glacial till	0.56	7.0	26.0	0.10	2.4	0.25

[1] A complete description of soil types can be found in Soils Report 12, Dept. of Soil Science, University of Saskatchewan, Saskatoon, Sask.
[2] Conductivity of saturated extract.
[3] 1/100 CO^2 extraction.
[4] % C × 1.72 = % O.M.

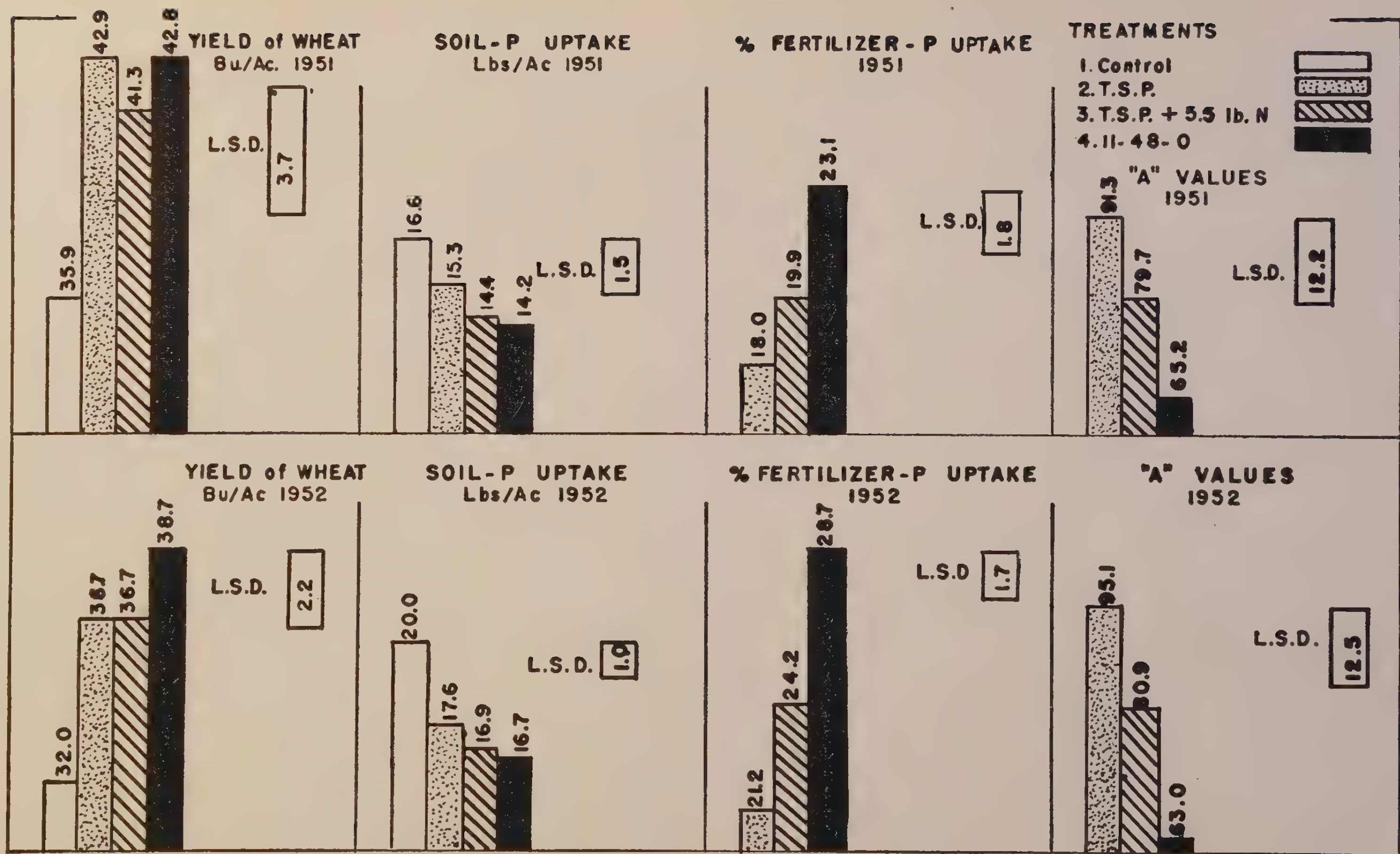

FIGURE 1. The average effect of treatments on yield, soil-P uptake, per cent fertilizer-P uptake, and "A" values. The 1952 data include the average of ten locations while those of 1951 reflect the mean of nine.

Both phosphate carriers were again applied at a rate of 24 lb. P_2O_5 per acre, thus ensuring a uniform rate of P_2O_5 for all fertilizer treatments. Treatments 3 and 4 contain an equivalent of 5.5 lb. N per acre, this rate being increased to 30 lb. of N for treatments 5 and 6.

All harvests were taken at maturity, dried and threshed to obtain the weight of grain and straw. The grain and straw were then ground separately. Total phosphorus was determined on both separates but the radio analysis was confined to the grain samples only.

The P^{32} radioanalysis was carried out as described by Kristjanson *et al.* (8) using the hollow cylinder technique. This method involves compressing the ground grain into a hollow cylinder which is then placed around a thin walled Geiger tube and counted directly.

For total analysis, the grain and straw samples were wet ashed by the method of Brenner and Harris (1) and phosphorus determined by the meta-vanadate method (7).

RESULTS

The complete report of the data obtained from the nine trials carried out in 1951 and the six smaller trials in 1952 is not given here but average values have been calculated and are reported in graphical form. While absolute values for yield, soil and fertilizer phosphate uptake and "A" values were considerably different for locations, the relative effect of the different treatments remained practically identical. As the same observations can be drawn from any one of the trials, the data have been summarized, and the average effect of treatments on yield, soil and fertilizer phosphate uptake and "A" values are illustrated in Figure 1.

On these fallow plots, all phosphate treatments, with or without added nitrogen, gave significant yield increases over the check in both years. In no instance did the addition of small amounts of nitrogen to T.S.P. result in a further increase in yield over that of the T.S.P. alone. While the yield responses to 11-48-0 and T.S.P. were practically identical in 1951, the differential responses obtained in 1952 illustrate the general superiority of the ammonium phosphates over superphosphates on high base status soils. These latter data are in accord with previous fertilizer tests (9).

A significant increase in fertilizer phosphate uptake occurred when an amount of nitrogen equal to that contained in 11-48-0 was added to T.S.P. This uptake, however, did not reach the level obtained in the application of 11-48-0. The availability of the phosphate carriers as measured by uptake were in the following order: T.S.P., T.S.P. plus 5.5 lb. N, and 11-48-0. The percentage uptake was significantly different for each treatment, and this result was consistently verified at all locations in both years.

Soil phosphorus uptake follows an interesting pattern. The greatest amount of soil phosphate is, of course, utilized when no fertilizer phosphate is applied, as in the case of the control. Where T.S.P. was applied, the plant obtained some of its phosphate from the fertilizer, and less soil phosphorus was taken up. As the availability of T.S.P. is increased by applications of NH_4NO_3, the plant preferentially extracts more of its

phosphate requirements from the more available fertilizer, with the result that less soil phosphate is utilized than was the case where T.S.P. was applied alone. The least amount of soil phosphate is taken up where 11-48-0 was used as the phosphate source. Since soil phosphate uptake decreases as the availability of the phosphate carrier increases, soil phosphate data can be used as a further indicator of fertilizer phosphate availability.

Fried and Dean (6) have proposed that the amount of soil phosphate available during the growth of a plant under specific environmental conditions can be calculated in the following manner:

$$\frac{\text{Per cent plant } P_2O_5 \text{ derived from the soil}}{\text{Per cent plant } P_2O_5 \text{ derived from the fert.}} \times \text{lb. } P_2O_5 \text{ applied} = \text{"A" value.}$$

The "A" value is defined as pounds per acre of available soil phosphorus in terms of the fertilizer used.

In every instance where NH_4NO_3 was added to T.S.P., marked reductions in A values occurred. Since there is no evidence in these data that would indicate a change in the availability of the soil phosphorus, the only conclusion that can be reached is that the added nitrogen has changed the characteristics of the fertilizer in such a manner as to make it more available to the plant.

Paired Fallow and Stubble Plots, 1952

The plot sites were selected in the early spring, the stubble locations being carefully chosen in areas where a particularly heavy trash cover remained from the previous crop. Prior to seeding, however, the stubble on the Watson plot was unintentionally burned. Growing conditions were satisfactory at both locations during the summer. A rather severe wild oat infestation reduced the grain yields on the Watson fallow plot.

The observations already drawn from the data of the smaller plots are verified in the data which were obtained from the four larger plots at Watson and Birch Hills, given in Table 2.

The addition of greater amounts of NH_4NO_3 to T.S.P. only accentuated the results previously discussed. For example, it is now evident that the availability of this mono-calcium phosphate fertilizer can be enhanced to a point where it exceeds that of the ammonium phosphate carrier, providing sufficient NH_4NO_3 is added.

In these data, the addition of nitrogen to T.S.P. or 11-48-0 appears to have had very little effect on yield (whether on fallow or stubble land) even though rates approximating 100 lb. per acre of NH_4NO_3 were used. However, a trend towards yield increases is evident on the stubble plots as the rate of nitrogen additions was increased, and in one instance on the Birch Hills stubble plot a significant yield increase did occur where 30 lb. of nitrogen were added to T.S.P. over that of the T.S.P. treatment alone.

While the relative effect of nitrogen additions to either T.S.P. or 11-48-0 on fertilizer uptake is similar for either fallow or stubble plots, the magnitude of these effects is much greater on the stubble land. At Birch Hills, the addition of 30 lb. of nitrogen as NH_4NO_3 to T.S.P. resulted in a 13.5 per cent increase in fertilizer uptake on fallow, and a 150 per cent

TABLE 2.—EFFECT OF NITROGEN ADDITIONS TO TWO PHOSPHATE CARRIERS ON YIELD, AND PHOSPHATE UPTAKE FROM ADJACENT FALLOW AND STUBBLE PLOTS AT TWO LOCATIONS

A. *Melfort Silty Clay Loam* (Birch Hills, Sask.)

Treatment	Fallow			Stubble		
	Grain yield, bu./ac.	Per cent fert. P uptake	A values	Grain yield, bu./ac.	Per cent fert. P uptake	A values
Check	33.8	—	—	25.8	—	—
T.S.P.	44.2	33.0	70.1	23.4	12.5	132.0
T.S.P. + 5.5 N	44.2	34.5	61.6	—	—	—
T.S.P. + 30 N	43.1	37.5	49.6	30.0	31.2	53.1
11-48-0	45.3	40.8	52.5	26.8	22.5	73.8
11-48-0 + 24.5 N	45.5	44.0	43.9	28.6	38.7	36.1
L.S.D.	4.8	3.6	6.3	3.5	3.8	15.4

B. *Yorkton Loam Soil* (Watson, Sask.)

Treatment	Fallow			Stubble		
	Grain yield, bu./ac.	Per cent fert. P uptake	A values	Grain yield, bu./ac.	Per cent fert. P uptake	A values
Check	30.0	—	—	40.0	—	—
T.S.P.	32.8	15.7	87.7	43.5	14.5	144.7
T.S.P. + 5.5 N	33.1	20.6	63.9	47.3	18.9	112.7
T.S.P. + 30 N	33.9	27.6	37.9	46.4	28.6	62.3
11-48-0	35.8	24.6	50.9	45.4	21.3	89.6
11-48-0 + 24.5 N	33.8	31.8	30.1	46.0	33.5	46.7
L.S.D.	3.2	2.6	10.5	N.S.	2.62	12.7

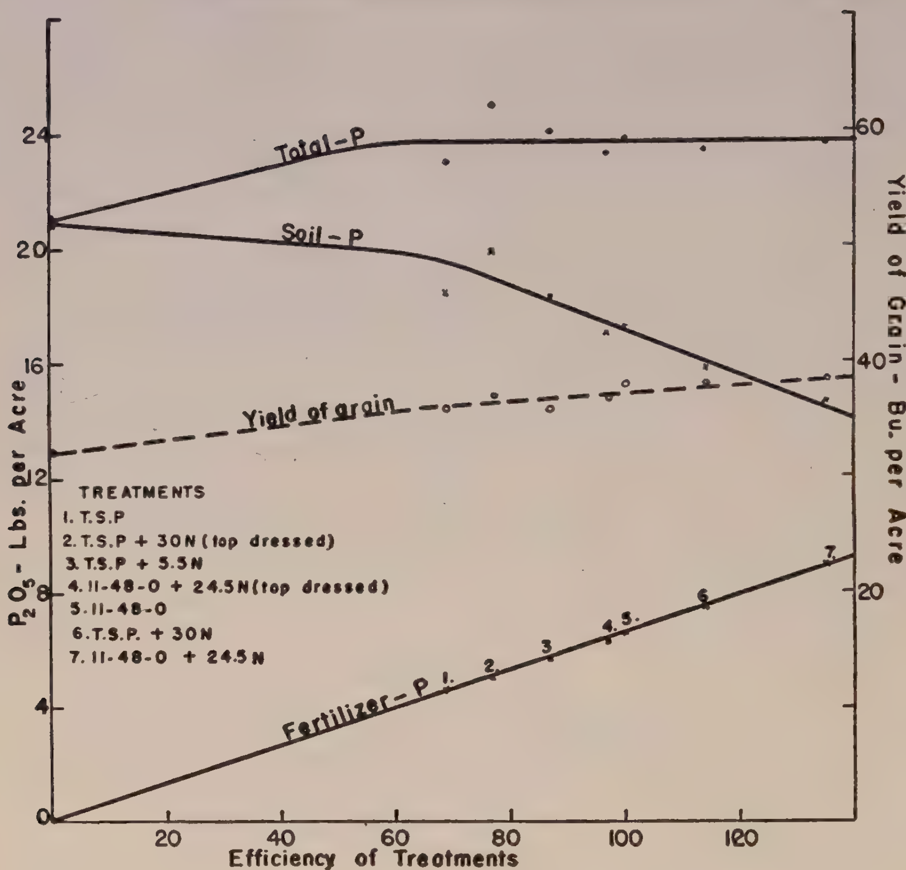

FIGURE 2. Effect of nitrogen additions on fertilizer-P, soil-P, and total-P in the grain and straw.

increase on stubble. Similarly, the addition of an equivalent amount of nitrogen to 11-48-0 resulted in a 7.8 and 72 per cent increase in uptake on fallow and stubble, respectively. On the burned-off stubble plot at Watson, the absolute uptake values are practically identical to those obtained on the fallow plot. Thus stubble trash obviously affects phosphate availability to a considerable extent. This reduction in phosphate availability is, however, partially overcome by the addition of nitrogen.

The "A" values for fertilizer treatments on the stubble plots in general are considerably higher than those for similar treatments on fallow. While this indicates a higher level of available phosphate in the stubble land, evidence will be presented later that suggests the reverse may be more correct.

A graphical illustration of the effects of increasing additions of nitrogen on fertilizer phosphate availability is given in Figure 2. The data used are the average of those obtained from the four larger trials conducted in 1952. The graph is self-explanatory with the possible exception of the units plotted on the y-axis (efficiency of treatments) which was determined

as follows: The 11-48-0 treatment was arbitrarily assigned an efficiency of 100 per cent and those of the remaining treatments were either greater or less than this depending on whether phosphate uptake was greater or less. It is to be noted that variations in the efficiency of the T.S.P. or 11-48-0 treatments were due only to varying amounts of NH_4NO_3 added to the respective carriers.

Fertilizer phosphate uptake increases, while soil phosphate uptake decreases, as the efficiency of the treatment increases. Total phosphate in the plant increases initially, reaches a maximum and then levels off. Yield of wheat in bushels per acre follows a similar pattern to that of the total phosphorus.

This notable effect of nitrogen additions on fertilizer phosphate, soil phosphate and total phosphate uptake is almost identical to that presented by Mitchell *et al.* (10), but these latter data, obtained in 1950, represent the effect of increased P_2O_5 applications (11-48-0) on phosphate uptake. It is rather significant that practically identical trends can be obtained whether P_2O_5 rate is held constant and nitrogen varied as is the case illustrated in Figure 2, or where increasing applications of P_2O_5 are made.

DISCUSSIONS AND CONCLUSIONS

The addition of NH_4NO_3 to two phosphate carriers, mono-ammonium phosphate (11-48-0) and mono-calcium phosphate (T.S.P.) has not resulted in significant yield responses on fallow land. As the fallow crops were grown on widely different soil types and under differing climatic conditions, it can be concluded that the level of available nitrogen in the fallow land was sufficient to produce a satisfactory yield of cereal grains. Thus the added nitrogen, under the conditions of these experiments, has had little value as a nutrient.

The availability of any phosphate carrier in high base status soils (whose base exchange complex is saturated with calcium) is determined first by its solubility and then by the rate at which the dissolved phosphate is transformed into an unavailable calcium phosphate. Although mono-calcium phosphate is somewhat less soluble than mono-ammonium phosphate, the former is sufficiently soluble to adequately supply the plants' requirements. The rate of fixation of the dissolved phosphate, however, is markedly influenced by any factor that would alter the calcium or hydrogen ion concentration in the vicinity of the fertilizer (12). Increased calcium ion concentration should depress availability. On the other hand, the addition of an acid-forming product, such as NH_4NO_3, would be expected to increase its availability. Mitchell *et al.* (11) have shown that small additions of elemental sulphur could greatly increase the availability of the phosphorus in a fertilizer which otherwise gave poor availability. For example, the addition of sulphur to a di-calcium phosphate carrier gave results equivalent to 11-48-0 in availability and yield increases in greenhouse tests. Through the action of sulphur-oxidizing bacteria, the addition of elemental sulphur would lower the pH in the vicinity of the fertilizer. For these reasons the addition of NH_4NO_3 to either T.S.P. or 11-48-0 should be expected to increase the availability of the phosphate carriers.

This reasoning has been verified in these data since, in every instance, a marked interaction between nitrogen additions and phosphate availability is apparent. In these experiments, the effect of the addition of a non-acidic nitrogen carrier was not investigated. In 1948, Dion *et al.* (3) added calcium nitrate to mono- and di-calcium phosphate and to mono-ammonium phosphate carriers. No significant increase in fertilizer phosphate uptake occurred.

Furthermore, under the conditions of the fallow experiments, there is little possibility that the nutritional value of the nitrogen in 11-48-0 is responsible for the superiority of the ammonium phosphate fertilizer over other phosphate carriers. The ammonium ion content of 11-48-0 would ensure local increased concentration of acidity in the vicinity of the fertilizer (through the action of the nitrifying bacteria) and thus reduce the fixation rate considerably.

Perhaps the most significant fact revealed by this study is the rather divergent data obtained on the stubble plots, as compared to those of the fallow. It was previously pointed out that a higher level of available soil phosphate (as indicated by the "A" value data in Table 2) probably was present in the stubble land. And in accordance with this conclusion, response to the applied phosphate fertilizers was least on the stubble land. In Saskatchewan, it has generally been assumed that the poor response to phosphates on stubble land was due to a lack of moisture reserves in the soil. These "A" value data suggest that on stubble land yield response to phosphate fertilizer should be approximately one-half as great as those obtained on fallow because of the higher soil phosphate availability in the stubble land.

However, the interpretation of "A" values as defined by Fried and Dean (6) could be subject to error. For example, the "A" values for the stubble land may be higher than on fallow because of a higher rate of fixation (in this instance, biological fixation) of the fertilizer phosphate. The lower uptake from either T.S.P. or 11-48-0 on stubble, coupled with the marked increase in this uptake due to nitrogen additions, indicates that this latter explanation may be of greater significance.

While an increase in available soil phosphate, or a decrease in the availability of the fertilizer phosphate would result in the noted high "A" values on stubble land, the practical interpolations of either explanations are widely divergent. If the higher "A" values indicate a higher level of available soil phosphate, then it should be unnecessary to apply phosphate fertilizers to stubble land. On the other hand, higher rates of fertilizer application than are currently recommended should be suggested in order to overcome the temporary utilization of fertilizer phosphate by the soil micro-organisms. These and other matters concerning phosphate availability on stubble land are currently under investigation.

ACKNOWLEDGMENT

The authors are indebted to E. Penner for his assistance in this study. Financial assistance from the Consolidated Mining and Smelting Company of Canada, Ltd., is gratefully acknowledged.

REFERENCES

1. Brenner, M. W., and P. L. Harris. An improved method of wet ashing of biological materials. Chem. Anal. 28 : 55-56. 1939.
2. Dion, H. G., J. W. T. Spinks, and J. Mitchell. Experiments with radioactive phosphorus on the uptake of phosphorus by wheat. Sci. Agr. 29 : 167-172. 1949.
3. Dion, H. G., J. E. Dehm, and J. W. T. Spinks. Study of fertilizer uptake using radioactive phosphorus. IV. The availability of phosphate carriers on calcareous soils. Sci. Agr. 29 : 512-526. 1949.
4. Fertilizer trials, Department of Soil Science, University of Saskatchewan. (*Mimeographed*). 1947, 1948, 1949, 1950 and 1951, inclusive.
5. Fertilizer trials, Department of Soil Science, University of Saskatchewan. (*Mimeographed*). 1952.
6. Fried, M., and L. A. Dean. Research Report 197, U.S.D.A. 1950.
7. Kitson, R. E., and M. G. Mellon. Colorimetric determination of phosphorus in molybdovanado-phosphorus acid. Ind. Eng. Chem., *Anal.* 16 : 379-383. 1947.
8. Kristjanson, A. M., H. G. Dion, and J. W. T. Spinks. Measurement of P^{32} in plants by counting hollow cylinders of compressed plant material. Can. J. Tech. 29 : 496-501. 1951.
9. Mitchell, J. The effects of phosphate fertilizers on summerfallow wheat crops in certain areas of Saskatchewan. Sci. Agr. 26 : 566-577. 1946.
10. Mitchell, J., A. M. Kristjanson, H. G. Dion, and J. W. T. Spinks. Availability of fertilizer and soil phosphorus to grain crops and the effect of placement and rate of application on phosphorus uptake. Sci. Agr. 32 : 511-525. 1952.
11. Mitchell, J., J. E. Dehm, and H. G. Dion. The effect of small additions of elemental sulphur on the availability of phosphatic fertilizer. Sci. Agr. 32 : 311-316. 1952.
12. Russell, E. J. Soil conditions and plant growth. 8th ed. Longmans, Green and Company, Toronto. 1950.
13. Spinks, J. W. T., and S. A. Barber. Study of fertilizer uptake using radioactive phosphorus. Sci. Agr. 27 : 145-156. 1947.

THE NATURE AND DISTRIBUTION OF SALINE SOILS IN MANITOBA[1]

L. E. PRATT[2] AND J. H. ELLIS[3]

Manitoba Soil Survey, Soils Department, The University of Manitoba, Winnipeg, Man.

[Received for publication November 24, 1953]

ABSTRACT

An investigation was conducted to determine the nature and distribution of saline soils in Manitoba. It was found that small, scattered areas of salinized soils occur over most of the non-forested region of Manitoba and occasionally within the forested region where special conditions such as saline springs or surface gypsum deposits exist. The principal soluble salts in the saline soil samples that were analysed were sulphates and chlorides of magnesium, calcium, and sodium. The proportion of sulphate to chloride varied in samples from different areas. Most of the saline soils were high in sulphates, while high concentrations of chlorides were restricted to specific soil areas. Appreciable amounts of sodium carbonate were not found in any of the saline soils tested and this salt does not appear to be common in Manitoba soils. The main cause of salinization of soils in Manitoba was found to be local impeded drainage.

INTRODUCTION

The occurrence of local areas in Manitoba, where the productivity of the soil is impaired by the presence of excessive amounts of soluble salts, has been known since the time of the early settlers. The distribution and extent of these areas has been determined over most of the agricultural portion of the province through the operations of the Manitoba Soil Survey. The mapping of saline soils by this survey has been based on morphological features expressed in the soil profiles, such as pseudo-mycelium and crystalline gypsum, together with observations of native vegetation or crop growth. Wherever saline soils were observed in the field, their occurrence was recorded on the field map and the extent of the larger areas shown by boundaries. At the time the soils were mapped the degree of salinity was estimated through observations on the species of native plants and the vigour of growing crops within the areas, and the results were shown by use of symbols denoting slightly saline, saline and strongly saline soils.

Investigations to determine the amount and composition of the soluble salts have been limited mainly to areas of special interest and to soil samples submitted to the Soils Laboratories of The University of Manitoba by farm operators. The limited quantitative and qualitative analyses that have been conducted have indicated that the sulphates of calcium, magnesium, and to a lesser extent sodium, are the chief constituents of soluble salts in most areas, but that high concentrations of chlorides occur in some regions.

The absence of appreciable amounts of soluble carbonates in nearly all the saline soils that have been tested and the lack of significant amounts of exchangeable sodium in the solonetzic soils of the Red River Valley, as determined by Ellis and Caldwell (1), have led to the general conclusion that

[1] Presented before the Soils Section, Agricultural Institute of Canada, Saskatoon, June 24, 1953. Adopted from a thesis submitted by L. E. Pratt in partial fulfilment of the requirements for the degree of Master of Science.

[2] Agricultural Research Officer, Canada Department of Agriculture, Winnipeg, Man.

[3] Professor of Soils, The University of Manitoba.

high concentrations of sodium carbonate are not common in Manitoba soils. This has been supported by the field observations of the Manitoba Soil Survey.

The investigation upon which this paper is based was undertaken to ascertain the nature of soil salinity in different parts of the province and the concentrations at which the soluble salts occur.

INVESTIGATIONAL PROCEDURE

Sixty-one representative saline soils were sampled to a depth of 48 inches. The soil areas were selected with the aid of the Manitoba Soil Survey maps and the sample sites chosen to represent the most saline soils within these areas. A detailed description of each sample site was recorded, with particular attention paid to: textural changes within the soil; soil moisture conditions and ground-water level; and the topographical position of the site.

After the samples had been air-dried and ground to pass through a 2-mm. sieve, composite samples of the borings from each sample site were prepared. The subsequent analyses were conducted on these composite samples rather than on the individual depth samples because the primary aim of the investigation was to obtain information on the kind of salts in these soils and not their distribution within the soil profiles, which is subject to variation with changes in soil moisture conditions. The 1 : 1 extracts of 36 of these samples were analysed quantitatively for soluble salts according to the methods outlined in the United States Regional Salinity Laboratory Publication (2). The extracts were also tested for electrical conductivity on a RC – 120 – 1 Model Conductivity Bridge. The total salt content of the remaining 25 composite samples was estimated from the electrical conductivity of their saturation extracts by means of a graph obtained by plotting the conductivity of the 36 chemically analysed samples against their known total salt content. Qualitative tests for sulphates, chlorides, carbonates, and nitrates were also conducted on these samples.

FIELD AND LABORATORY DATA AND DISCUSSION OF RESULTS

To facilitate a discussion of the results of these field and laboratory investigations, the agricultural portion of Manitoba has been divided into four physiographic areas:

A. Western Upland area.
B. Souris Basin and Assiniboine Delta area.
C. Agassiz Basin and Lowland area.
D. Eastern Upland area.

The location of these areas is shown in Figure 1.

A. Western Upland Area:

Over most of the Western Upland area the soils are developed on mixed boulder till containing a considerable amount of shale in some parts. Shallow deposits of lacustrine and deltaic material over the till occur within this area, notably in the valley of the Swan River between the Porcupine

MAP OF MANITOBA
(SOUTHERN PORTION)
SHOWING
PHYSIOGRAPHIC AREAS

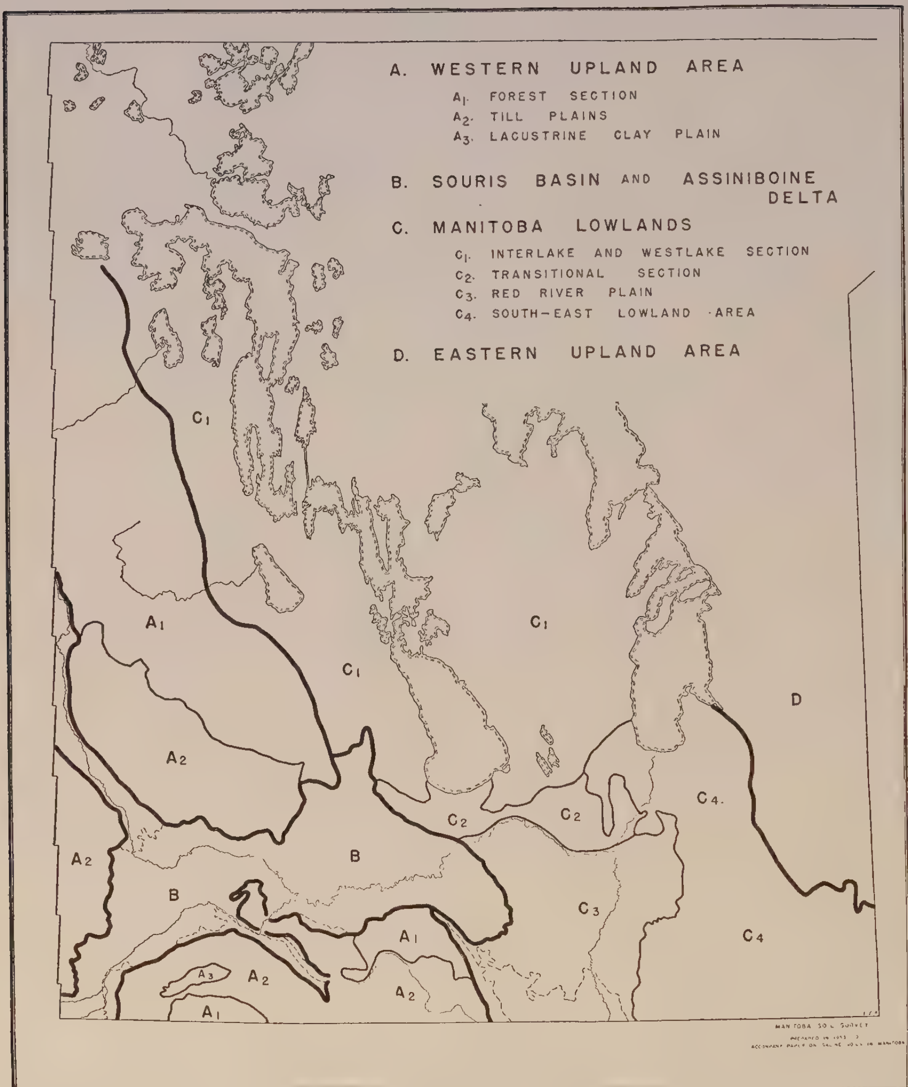

FIGURE 1.

and Duck Mountains, the broad valley between the Duck and Riding Mountains, and the basinal area to the north of the Turtle Mountain.

As a consequence of climatic and vegetational differences, variations exist in the dominant soil-forming processes operative in different parts of the area. Over a large part of the northern portion and on the higher land of the Turtle Mountain and Pembina Hills in the southern portion,

the atmospheric climate is somewhat cooler, the soil climate more humid than in the rest of the area, and the soils have developed under woods. Here, Grey–Black and Grey Wooded soils are the dominant types, and the associated hydromorphic soils are usually Peaty Meadow or Organic soils. In the less elevated portion of the region, the conditions under which the soils have developed are somewhat drier, due to a warmer climate, and grassland soils are the dominant types.

In the forest regions of this area, which are denoted as A_1 (Figure 1), saline soils do not commonly occur. The soluble salts which result from the weathering of the soil minerals do not accumulate in the upper portions of the profile, but are leached downward and carried away in the drainage waters. In the boulder-till area of the aspen grove and grassland region, denoted as A_2 (Figure 1), salinized soils are of a common occurrence. Characteristic of this region is the occurrence of undrained depressional areas varying from small potholes and sloughs in the undulating portions to large meadows and intermittent lakes in the smoother areas. These depressional areas act as local catchbasins for run-off water and subsurface lateral seepage from the surrounding higher land. In wet spring seasons and in periods of heavy rainfall, they are flooded by water and, because of a high water table or impeded internal drainage, the percolation of this water into the soil is retarded and a large portion of it evaporates, leaving behind the soluble salts it has derived from the minerals in the soils of the surrounding area (see Figure 2). This concentration may be supplemented in some cases by upward movement of ground water in dry seasons. Chemical analyses of eleven composite profile samples from this area indicated that the dominant anion in the saline soil solutions is invariably the sulphate ion. Chlorides were also present, but in low concentrations. Soluble carbonates and nitrates were not found in measurable quantities in any of the samples tested. Bicarbonates usually made up 1 or 2 per cent of the anions, being present in amounts varying from about 100 to 350 p.p.m. Some variation existed in the proportions of the cations present. Magnesium was dominant in 6 of the samples and the alkali cations in the other 5. The total salts present in these composite samples ranged up to 24,097 p.p.m. Higher concentrations would have been found had the various sample depths been tested individually. The reaction of the samples varied from pH 7.95 to 8.75. The results of these analyses are shown in summary form in Table 1.

The soils developed on the lacustrine clay which surrounds the intermittent Whitewater Lake, in the southwest corner of the province, are a complex of immature soils showing varying degrees of profile development in the process of transition from hydromorphic through salinized to well-drained soils. The area, denoted as A_3 (Figure 1), acts as a catchbasin for the run-off water from the Turtle Mountain and the adjacent plain. The internal drainage is very slow and large areas of strongly salinized soils occur. Analysis of two samples from this area indicated that sodium sulphate forms a large part of the soluble salts. Chlorides and bicarbonates were present in small amounts. The cations consisted of about 70 or 80 per cent sodium and small amounts of magnesium and calcium. The total salts ranged from about 23 to 28 thousand p.p.m. and the soil reaction was

8.65. The averages of these analyses are shown in Table 1. The higher concentration of sodium sulphate in these soils is in conformity with soluble salt analysis of water samples from the Tertiary rock formations of the Turtle Mountain.

B. Souris Basin and Assiniboine Delta Area:

Most of the soils in the Souris Basin and Assiniboine Delta area, denoted as B (Figure 1), are developed on medium textured and sandy deltaic materials which were deposited in the shallow waters of Glacial Lake Agassiz by rivers and streams flowing from the west and south. Grassland soils are the dominant type. For the purpose of a discussion of the salinized soils, the area has been subdivided into three sections:

(1) Lacustrine and delta deposits;
(2) River and lake terraces;
(3) Eroded river channels.

The soils developed on sandy lacustrine and delta materials in the Souris Basin and Assiniboine Delta area are almost invariably free of high concentrations of soluble salts, even though the ground-water table is within a few feet of the surface in many local regions. The high permeability of these soils is undoubtedly an important factor contributing to this absence of salinization, but also, a study of well records reveals that the water in these sandy deposits is normally very low in soluble salts. Salinization has occurred over small acreages in the medium textured soils of the Souris Basin. Wherever saline areas were encountered on these soils it was found that the internal drainage was impeded by a heavier textured substratum of heavy clay loam or silty clay lacustrine material or heavy clay loam boulder till. Only one sample from this sub-area was analysed quantitatively and the results are shown in Table 1. The salts consisted mainly of calcium and magnesium sulphate. The pH of the soil was 7.80 and the total salt content 3,026 p.p.m. Qualitative analyses of other samples indicated a similar type of salinity.

On the terraces which occur in the broad valleys of the Souris and Assiniboine rivers, in the wide channel of the Lake Souris outlet and along the north side of the Tiger and Pembina Hills, the soils have been developed on an assortment of materials. These terraces were originally cut in the mixed boulder till, and stony water-worked till forms the parent materials of the soils in some places. Elsewhere, the soils were developed on thin deposits of outwash gravel and sand and overwash shale clay which were laid down over the water-worked till. The topography of these terraces is usually flat with micro-depressions and salinized soils are found in the lower positions where the internal drainage is impeded by a change of texture within the profile. Samples from these areas showed a wide variation in their total salt content, but similarity did appear in the kind of salts present. The anions were found to be largely sulphates in all soils tested and calcium, magnesium and alkali cations were all present in substantial amounts. Trace amounts of carbonates were found in two samples, while all soils gave negative tests for nitrates. The average results of the quantitative analyses of two composite samples are given in Table 1.

TABLE 1.—AVERAGE ANALYSES OF SALINE SAMPLES FROM PHYSIOGRAPHIC AREAS IN MANITOBA. CATION AND ANION MILLI-EQUIVALENTS EXPRESSED AS PERCENTAGES OF THEIR TOTALS

Physiographic areas and sub-areas	Number of samples	Cations Milli-equivalents Expressed in per cent			Anions† Milli-equivalents Expressed in per cent			Total salts (p.p.m.)	pH
		Ca	Mg	Na*	SO_4	Cl	HCO_3		
A. WESTERN UPLAND AREA:									
A_1. Forest section									
A_2. Till plains	11	16.7	39.9	43.4	90.5	7.4	2.1	12,646	8.3
A_3. Lacustrine clay plain	2	7.5	17.5	75.0	97.0	2.0	1.0	26,064	8.6
B. SOURIS BASIN AND ASSINIBOINE DELTA AREA:									
Lacustrine and delta deposits	1	41.0	52.0	7.0	91.0	3.0	6.0	3,026	7.8
River and lake terraces	2	25.0	43.0	32.0	86.0	4.0	10.0	4,159	8.1
Shale clay in eroded river channels	2	20.0	24.0	56.0	81.5	15.0	3.5	9.716	7.6
C. AGASSIZ BASIN AND LOWLAND AREA:									
C_1. Interlake and Westlake section									
Saline spring area	1	10.0	10.0	80.0	11.0	88.0	1.0	40,521	7.0
Surface gypsum deposit area	1	23.0	56.0	21.0	73.0	12.0	15.0	2,125	8.3
High-lime till and lacustrine deposits	6	16.5	38.7	44.8	58.2	38.5	3.3	10,667	8.1
C_2. Transitional section	4	22.0	41.0	37.0	39.0	58.0	3.0	9,261	7.9
C_3. Red River Plain									
Lacustrine clay of central basin	2	25.0	58.5	11.5	93.5	2.0	4.5	5,927	7.8
Overwash shale clay	1	16.0	25.0	59.0	58.0	39.0	3.0	6,904	7.8
Deltaic deposits	2	32.0	54.0	14.0	46.0	46.0	8.0	4,452	7.9

* Alkali cations were obtained by difference and expressed as sodium.

† The samples were also analysed for carbonates and nitrates but no measurable quantities were found to be present.

In the central and western channels of the Souris River south of Melita and in the broad valley of the Lake Souris outlet, soils have been developed on clay deposits from weathered shale. These soils are highly impervious to water and, because of their low position, are subject to swamping. Consequently they have been salinized or solonized throughout the entire area. Analysis of samples taken to represent these soils indicated that the dominant salts are sulphates of sodium, magnesium and calcium, but that a high concentration of sodium chloride is present in the soils of the Lake Souris outlet. The average analyses are shown in Table 1.

C. Agassiz Basin and Lowland Area:

The area commonly referred to as the Manitoba Lowlands is the broad extent of land between the Manitoba Escarpment and the Eastern Upland area of Precambrian rock outcrop. This is the area that formed the basin of Glacial Lake Agassiz during the recession of the continental ice sheet. The surface deposits on which the soils have been developed vary considerably and for this reason the area has been divided into a number of sections for this discussion:

C_1 The Westlake and Interlake section;
C_2 The Transitional section;
C_3 The Red River Plain;
C_4 The Southeast Lowland section.

The parent material of the soils in the Westlake and Interlake section, denoted as C_1 (Figure 1), consists mainly of high-lime boulder till which was subjected to severe wave action in the shallow waters of Lake Agassiz. This reworking of the till has resulted in a ridge and swale type of topography throughout most of the area. Shallow deposits of lacustrine sediments often occur in the depressional areas. The soils are generally of the Rendzina or Degrading Rendzina type.

In the northern portion of this section, where the climate is somewhat cooler than farther south, the soils have been developed under woods and some degradation has occurred. In this region, the well-drained soils are Degraded Rendzinas and their poorly drained associates are mainly Organic or Peaty Meadow soils. Saline soils are not of general occurrence here. However, in certain portions of this region small areas of very strongly salinized soils do occur. These are the result of local conditions, namely: (1) Saline springs along the west shores of Lake Winnipegosis and Swan Lake; and (2) Surface gypsum deposits in the Gypsumville district of the Interlake area. In the saline spring area, the land surrounding the springs is continually being swamped by the salty water issuing from them (see Figure 3). The dominant salt in the brine is sodium chloride and this was found to be the dominant salt in the resulting salinized soils. The results of the analysis of one composite sample from a saline spring area on the shore of Dawson Bay, Lake Winnipegosis are given in Table 1. In the Gypsumville area, magnesium and calcium sulphates are the main salts in the soil solution.

In the southern portion of the Interlake and Westlake section, the climate is somewhat warmer and the better drained soils are of the Rendzina

FIGURE 2. View of saline soil in southwestern Manitoba, showing typical white efflorescence of salts and sparse vegetative growth on highly saline area.

FIGURE 3. View of local area in northern portion of the Westlake district of Manitoba which is being affected by overflow from saline springs. The normal vegetation of the region can be seen in the background.

type and usually effervesce with acid at the surface. The poorly drained soils are often found to be salinized to some degree. This is particularly true in the area bordering the south shore of Lake Dauphin; in the Big Grass Marsh area north of Gladstone; and along the east shore of Lake Manitoba. Saline soils in these areas are generally high in both sulphates and chlorides. Calcium, magnesium and sodium are all present in appreciable amounts. The average analysis representing 6 composite samples is given in Table 1.

Between this area of soils developed on high-lime boulder till and the heavy clay deposits of the Red River Plain, there is a transitional belt in which the clay sediments form a shallow covering over the till. This area, denoted as C_2 (Figure 1), is located north of the Assiniboine River and is distinguished from the main portion of the Red River Plain because it is influenced by drainage waters from the high-lime area to the north. In parts of the area, particularly in the district known as the Portage Plains, the soils have been developed on a shallow depth of lighter textured lacustrine and deltaic materials. These soils are highly fertile and not generally salinized to any appreciable extent.

Apart from the Portage Plains area, salinized soils are very common on the clay deposits in the transitional belt denoted as C_2 (Figure 1). The topography of the area is generally flat with some micro-relief and because of the very slow internal drainage, the soils in the low-lying areas are frequently covered with water for long periods in the spring and after heavy rains. A large volume of the water does not percolate into the soil but evaporates from the surface, leaving behind the salts it has dissolved from the soils on the surrounding higher land. This accumulation of soluble salts in the slightly depressed portion of the land causes a characteristic unevenness of the crops, which is especially noticeable in drier seasons when the salts are concentrated near the surface through the high capillary rise of round water in these clay soils. The saline soils in this area are high in both sulphates and chlorides. The total salt content of the samples taken varied from 1,500 to 15,700 p.p.m. The pH determinations indicated that the saline soils in this area are slightly less alkaline in reaction than those in the western part of the province. The average results of the analyses of 4 composite samples are given in Table 1.

In the area commonly known as the Red River Plain, denoted as C_3 (Figure 1), the soils are developed on clay, silt and sand deposits of Glacial Lake Agassiz. Heavy lacustrine clay covers the major portion of the region but there is a narrow strip of land adjacent to the escarpment in which the soils are developed on shale clay overwash from the Pembina Hills, and east of this there is a broad extent of land on which the lacustrine clay deposits are covered by a variable depth of coarser textured lacustrine, delta and recent alluvial materials.

Over a large portion of the clay basin area in the Red River Plain, the soils were developed under conditions of poor drainage and accumulation of soluble salts in the surface horizons was certain to occur. However, since the days of early settlement the drainage of these soils has been greatly improved through the installation of an extensive system of artificial drains. As a consequence of this improvement in drainage, the soils over

a large part of the area have become desalinized, solonized, and in some places solodized. However, slightly salinized hydromorphic soils still occur in the depressional areas. The analyses of samples from this area indicated that the main constituents of the saline soil solutions are sulphates of magnesium and calcium. Chlorides were not found in high concentrations in any of the samples tested and the alkali cations were low in all samples. Here again, the pH of the saline soils was slightly lower than in the western part of the province.

Most of the soils which have been developed on the clay overwash from the Cretaceous shales of the escarpment are salinized or alkalinized, depending on their drainage conditions. These soils contain a high percentage of bentonitic clay and are therefore very impervious to water. As they occur in an area which is continually subject to seepage water from the adjacent higher land, the accumulation of salts in the depressions is easily understood. The salts in these soils are high in both sulphates and chlorides, and sodium is the dominant cation.

In the area where the soils are developed on delta and recent alluvial deposits over the lacustrine clay, salinized soils are found only where the internal drainage is impeded by a heavy textured subsoil. In the rest of the area the soils are generally well-drained and soluble salts have not accumulated in the upper horizons of the profiles. Here again the saline soils were found to contain high concentrations of both sulphates and chlorides. The cations were dominantly magnesium and calcium.

In the Southeast Lowland section, denoted as C_4 (Figure 1), the soils have been generally developed under forest vegetation, as a result of a somewhat cooler and more humid climate, and the poorly drained soils are not often salinized.

D. Eastern Upland Area:

The Eastern Upland area in Manitoba, denoted as D (Figure 1), represents a portion of the Laurentian Shield and is characterized by large areas of granitoid rock outcrop. Where glacial material and lacustrine sediments occur over the rocks, podzolic soils have been developed under an acid leaching process. Saline soils are not formed under these conditions.

CONCLUSIONS

(1) Small scattered areas of salinized soils occur over most of the non-forested region of Manitoba, and occasionally in the forested region where special conditions such as saline springs or surface gypsum deposits exist.

(2) The general source of the salts, which accumulate in the upper horizons of the soils where the internal drainage is impeded by an impervious subsoil or a high water table, is the weathering of the soil minerals in the surface deposits of the surrounding area or the areas from which drainage waters originate.

(3) The principal soluble salts in these soils are sulphates and chlorides of magnesium, calcium and the alkali cations.

(4) The proportion of sulphates to chlorides in the salinized soils varies with different areas.

(5) Most of the saline soils in the province are high in sulphates, while high concentrations of chlorides seem to be restricted to:

(*a*) The saline spring areas in the northern part of the Westlake region;
(*b*) The soils developed on shale clay in the glacial Lake Souris outlet;
(*c*) The transitional area between the heavy clays of the Red River Plain and the calcareous boulder till of the Interlake and Westlake regions.

(6) Black alkali soils, or soils containing appreciable amounts of sodium carbonate, are not commonly found in Manitoba.

REFERENCES

1. Ellis, J. H., and O. G. Caldwell. Magnesium clay solonetz. Trans. 3rd Int. Cong. Soil Sci.1 : 348-350. 1935.
2. Hayward, H. E., and L. H. Richards *et al.* Diagnosis and improvement of saline and alkali soils. U.S. Regional Salinity Lab., Riverside, Cal. 1947.

FERTILITY STUDIES ON SOIL TYPES

IV. POTASSIUM SUPPLY AND REQUIREMENT AS SHOWN BY GREENHOUSE STUDIES AND LABORATORY TESTS[1]

R. F. Bishop[2], A. J. MacLean[3] and L. E. Lutwick[4]

Canada Department of Agriculture, Ottawa

[Received for publication December 22, 1953]

ABSTRACT

Oats and alfalfa were grown in the greenhouse on samples of surface soil taken from nine farms on each of ten soil types occurring in the Ottawa district. The effect of applied potassium, as shown by alfalfa yields and the combined uptake of potassium by oats and alfalfa, was used as a basis for evaluating the Neubauer procedure and two chemical procedures as methods for estimating the soil potassium available for plant growth.

The relative effect of applied potassium on the uptake of potassium varied significantly according to soil type.

The amounts of potassium extracted from surface soil samples, by each of the three methods employed, varied significantly between soil types. Correlation coefficients, expressing the relationship between clay content and soil potassium extracted, were highly significant for each of the three methods.

The correlation coefficients relating the uptake of potassium by the crops and the results obtained by the three methods employed were highly significant.

The phosphorus supply and requirement of ten soil types occurring in the vicinity of Ottawa, Ontario, have been given in a previous publication (4). Information on the potassium status of these soil types, obtained through greenhouse and laboratory studies of composite samples of surface soil from cultivated fields, is presented in the present paper. These soils have been described in soil survey reports (3, 6) and the physical and chemical properties of the samples used in this study have been discussed in a previous publication (1).

MATERIALS AND PROCEDURE

Samples of surface soil from three farms on each of ten soil types were obtained in the fall of 1946. Similar sets of samples were taken from other farms in the fall of the two following years. For greenhouse tests the soils were air-dried, passed through a sieve with one-half inch mesh, mixed, and placed in glazed gallon pots on a volume basis. Samples of the air-dried soils were passed through a 2-mm. sieve and retained for analyses in the laboratory. Oats and alfalfa were seeded together in the fall of the year of sampling and later thinned to seven oat plants and ten alfalfa plants per pot. Fertilizers were placed in the soil at a depth of two inches, oat seeds at a depth of one inch, and alfalfa seeds at a depth of one-half inch. The treatments, relevant to this discussion, were 4-10-0 and 4-10-10 commercial fertilizers applied at the rate of 400 lb. per acre. The oats

[1] Joint contribution from the Chemistry Division, Science Service, and the Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service. Scientific Contribution No. 249, Chemistry Division.

[2] Chemist, Chemistry Division.

[3] Senior Agronomist, Division of Field Husbandry, Soils and Agricultural Engineering.

[4] Assistant Chemist, Chemistry Division.

were harvested in the spring and either three or four cuts of alfalfa were made during the summer. There were six replications for oats and three for alfalfa, except in the tests conducted in 1946-47 where there were twelve replications for oats and nine for alfalfa. The yields of grain, straw and alfalfa were obtained for each pot. The per cent potassium in each of these materials, grown with and without applied potassium, was determined using composite samples from all replications. The materials were ground in a Wiley mill and the potassium content determined according to the method of Garman (2).

Estimates of the soil potassium available for plant growth were obtained by the methods of Neubauer (7), by extraction with a sodium acetate solution at pH 4.85 as given by Peech and English (5), and by extraction with a neutral, normal ammonium acetate solution (7).

RESULTS AND DISCUSSION

Yields of Oats and Alfalfa in the Greenhouse

The mean yields of grain, straw and alfalfa grown with and without potassium fertilizer are presented, for each soil type, in Table 1. Considering the grain and straw together, there was little evidence that application of potassium had any beneficial effect on the yield of oats except on Uplands sand and Rubicon loamy sand. On the soils of heavier texture (Carp, North Gower and Rideau), potassium fertilizer (KCl) produced significant

TABLE 1.—EFFECT OF APPLIED POTASSIUM ON YIELD OF OATS AND ALFALFA IN THE GREENHOUSE

(Mean yield per pot for 9 tests on each soil type; fertilizer applied at 400 lb. per acre)

Soil type	Grain		Straw		Alfalfa (air-dry)	
	4-10-0	4-10-10	4-10-0	4-10-10	4-10-0	4-10-10
	gm.	gm.	gm.	gm.	gm.	gm.
Uplands sand	4.5	5.1	11.0	12.5	9.0	11.9
Rubicon loamy sand	5.7	5.8	12.0	13.5	8.3	14.2
Kars gravelly sandy loam	7.4	7.5	16.3	16.8	23.4	26.6
Grenville loam	9.4	9.5	17.0	17.8	18.2	20.5
Manotick sandy loam	7.7	8.1	16.2	15.9	14.8	17.5
Castor silt loam	7.6	7.6	15.7	15.5	12.7	16.0
Osgoode loam	7.3	7.0	14.4	13.9	14.7	18.5
Carp clay loam	9.2	8.6	20.1	18.2	21.9	22.1
North Gower clay loam	9.5	9.0	18.7	16.9	21.0	21.8
Rideau clay	10.2	9.4	23.1	20.8	22.6	24.7
L.S.D. (0.05)*	0.4		1.0		1.7	

* Based on pooled (potassium × farms) interaction within each soil type.

decreases in the yields of oats. With respect to alfalfa, the application of potassium resulted in significant yield increases on all soil types except the Carp clay loam and North Gower clay loam.

Per Cent Potassium in the Crops

The percentages of potassium in the grain, straw, and alfalfa crops grown with and without applied potassium are given as mean values for each soil type in Table 2. The application of potassium had only a slight effect on the potassium content of the grain on any of the soils. On the other hand, applied potassium increased appreciably the potassium content of the straw on most of the soils, the differences being significant except for the Carp clay loam and the Rideau clay. Under the conditions of this experiment, where oats preceded alfalfa, the relatively low rate of potassium employed had no pronounced effect on the potassium content of the alfalfa. The potassium content of the straw, and more particularly that of the alfalfa grown on the Carp, North Gower and Rideau soils, was relatively high in comparison with the values obtained on the other soil types. On these heavier textured soils, where application of potassium resulted in decreased oat yields, the potassium content of the straw grown on the treated soils exceeded 2 per cent.

TABLE 2.—EFFECT OF APPLIED POTASSIUM ON THE PER CENT POTASSIUM (K) IN OATS AND ALFALFA GROWN IN THE GREENHOUSE

(Mean values, air-dry basis, for 9 tests on each soil type; fertilizers applied at 400 lb. per acre)

Soil type	Grain		Straw		Alfalfa	
	4-10-0	4-10-10	4-10-0	4-10-10	4-10-0	4-10-10
	%	%	%	%	%	%
Uplands sand	0.49	0.53	1.24	1.92	0.61	0.72
Rubicon loamy sand	0.47	0.53	0.73	1.63	0.51	0.59
Kars gravelly sandy loam	0.51	0.53	1.44	1.78	0.70	0.70
Grenville loam	0.49	0.50	1.47	1.79	0.82	0.99
Manotick sandy loam	0.50	0.50	1.38	1.67	0.73	0.94
Castor silt loam	0.51	0.52	0.94	1.63	0.58	0.64
Osgoode loam	0.50	0.53	1.09	1.68	0.80	0.84
Carp clay loam	0.48	0.52	2.13	2.31	1.87	1.78
North Gower clay loam	0.49	0.54	1.73	2.04	1.26	1.48
Rideau clay	0.53	0.56	2.40	2.48	2.15	2.06
Average	0.50	0.53	1.46	1.88	1.01	1.07
L.S.D. (0.05)*	0.04		0.22		0.13	

* Based on pooled (potassium × farms) interaction within each soil type, and applicable to differences between the mean values given for each soil type.

TABLE 3.—AMOUNTS OF POTASSIUM (K) REMOVED PER POT BY THE OAT AND ALFALFA CROPS IN THE GREENHOUSE

(Mean values for 9 tests on each soil type; 4-10-10 treatment contained 90.8 mgm. K per pot)

Soil type	Oats		Alfalfa		Oats and alfalfa		Uptake on 4-10-0 as per cent of uptake on 4-10-10		
	4-10-0	4-10-10	4-10-0	4-10-10	4-10-0	4-10-10	Oats	Alfalfa	Oats + alfalfa
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.	%	%	%
Uplands sand	157.0	258.3	54.0	81.1	211.0	339.4	61	67	62
Rubicon loamy sand	119.3	243.7	38.3	82.6	157.6	326.3	49	46	48
Kars gravelly sandy loam	269.8	332.6	167.7	191.0	437.5	523.6	81	88	84
Grenville loam	286.7	361.5	172.0	230.1	458.7	591.6	79	75	78
Manotick sandy loam	266.8	308.7	106.0	153.0	372.8	461.7	86	69	81
Castor silt loam	193.9	285.5	76.7	104.5	270.6	390.0	68	73	69
Osgoode loam	192.2	267.8	134.6	164.3	326.8	432.1	72	82	76
Carp clay loam	467.4	455.3	416.0	403.1	883.4	858.4	103	103	103
North Gower clay loam	367.9	388.8	273.0	323.4	640.9	712.2	95	84	90
Rideau clay	601.5	567.5	485.2	502.8	1086.7	1070.3	106	97	102
L.S.D. (0.05) between treatments*	37.1		28.5		43.9				
L.S.D. (0.05) between soils**	138.1		136.0		213.2				

* Based on pooled (potassium × farms) interaction within each soil type.
** Based on pooled farm variance within each soil type.

TABLE 4.—ANALYSES OF VARIANCE OF DATA RELATING TO UPTAKE OF POTASSIUM BY OATS AND ALFALFA

Source of variation	Oats			Alfalfa			Oats and alfalfa		
	D.F.	M.S.	F	D.F.	M.S.	F	D.F.	M.S.	F
Soil type	9	282,160.86	180.86**	9	392,649.22	425.90**	9	1,326,437.71	607.22**
Farms within soil type	80	21,675.64	13.89**	80	21,013.20	22.79**	80	51,650.69	23.64**
Potassium	1	134,589.36	86.27**	1	43,895.33	47.61**	1	335,223.72	153.46**
Potassium × soil type	9	11,472.36	7.35**	9	1,867.87	2.03*	9	17,692.26	8.10**
Potassium × farms (error)	78	1,560.13	—	79	921.94	—	77	2,184.44	—

* Significant at 0.05.
** Significant at 0.01.

Potassium Removed by Crops

The average uptakes of potassium by oats, by alfalfa and by the two crops combined were calculated from the results for yield and composition. These average uptakes are presented for each soil type in Table 3. This table also includes the values of the uptake of potassium on the 4-10-0 treatment expressed as percentages of the uptakes on the 4-10-10 treatment.

The analyses of variance in Table 4 show that applied potassium resulted in highly significant differences in the uptake of potassium as measured by oats and by alfalfa. The interaction of the potassium treatment on soil type was highly significant for oats and significant for alfalfa; that is, the variation in the effect of applied potassium was greater between soil types than between farms on the same soil type. The variations in the uptake of potassium by oats and by alfalfa between different soil types and between farms on the same soil type were highly significant. However, the variation in the uptake of potassium by the crops on different soil types exceeded that occurring between farms on the same soil type at the 1 per cent level.

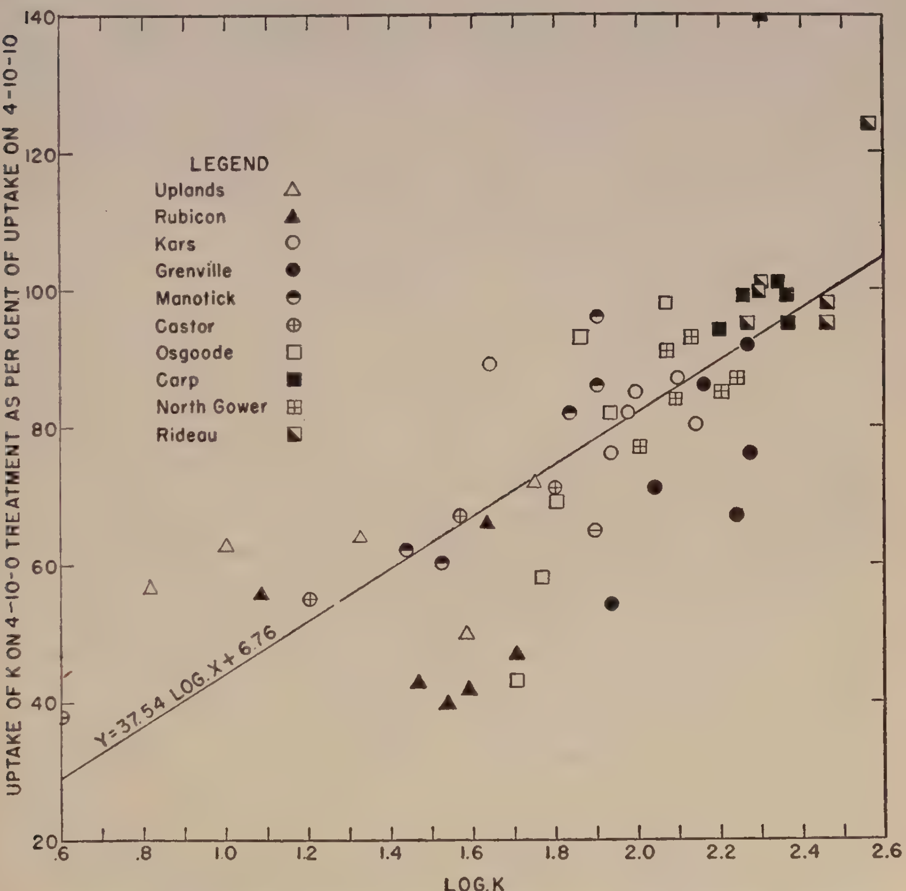

FIGURE 1. Relationship between soil K determined by the Neubauer procedure and greenhouse results.

The data in Table 3 show that the different soil types varied considerably with respect to the uptake of potassium on the 4-10-0 treatment expressed as a percentage of that on the 4-10-10. On the basis of the oats and alfalfa combined, the Rubicon, Uplands, and Castor soils showed the greatest response to applied potassium, whereas the Carp, Rideau, and North Gower soils showed the least. Under the conditions of this experiment, oats and alfalfa responded similarly to applied potassium on the individual soil types. However, the relatively low rate of potassium applied, luxury consumption of potassium by the oat crop and the fact that alfalfa succeeded the oats undoubtedly influenced the results obtained with alfalfa.

SOIL POTASSIUM EXTRACTED BY VARIOUS PROCEDURES

Estimates of 'available' soil potassium, as determined by the three methods used (5, 7), are presented as mean values for each soil type in Table 5. With each of the methods the variation in the amounts of

TABLE 5.—MEAN VALUES FOR POTASSIUM (K) EXTRACTED BY THREE PROCEDURES FROM SURFACE SAMPLES OF TEN SOIL TYPES

Soil type	Exchangeable (9)*	Peech and English (9)*	Neubauer (6)*
	p.p.m.	p.p.m.	p.p.m.
Uplands sand	53	34	33
Rubicon loamy sand	38	28	35
Kars gravelly sandy loam	52	38	97
Grenville loam	77	46	147
Manotick sandy loam	68	45	59
Castor silt loam	41	28	39
Osgoode loam	54	36	75
Carp clay loam	151	75	202
North Gower clay loam	124	59	135
Rideau clay	225	100	255
Average for all samples	88	49	108
Total number of samples	90	90	59
M.S. between soil types	32,988.9	4,652.19	34,425.8
M.S. within soil types	2,122.8	284.47	1,426.2
F value	15.54**	16.35**	24.14**

* Number of samples representing each soil type. The results of the Neubauer procedure on Castor silt loam are based on only 5 samples.

** Significant at 0.01.

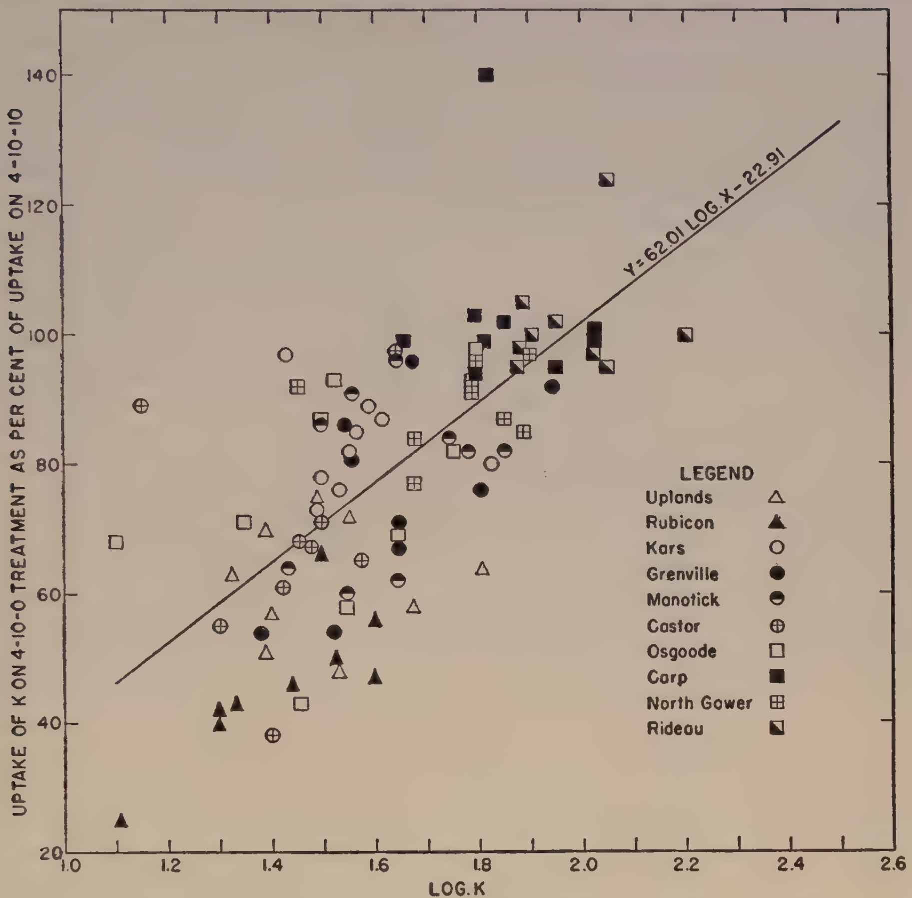

FIGURE 2. Relationship between soil K determined by the Peech and English procedure and greenhouse results.

potassium extracted from surface samples from different soil types exceeded the variation between samples from farms on the same soil type, at the 1 per cent level of significance. The values for exchangeable potassium and those obtained by the method of Peech and English were each significantly correlated with the Neubauer values, the correlation coefficients being + 0.867 and + 0.808, respectively. There was a significant corrélation coefficient (+ 0.650) between the values for exchangeable potassium and those obtained by the method of Peech and English.

All three methods showed that the amount of 'available' soil potassium increased with increasing clay content of the soils. The correlation coefficients, expressing the relationship between clay content and soil potassium extracted, were + 0.750 for exchangeable potassium, + 0.759 for potassium soluble in sodium acetate and + 0.889 for potassium extracted by the Neubauer method. Each correlation coefficient was significant at the 1 per cent level.

RELATIONSHIP OF 'AVAILABLE' SOIL POTASSIUM AND GREENHOUSE RESULTS

The correlation coefficients, expressing the relationship between soil test values and alfalfa yields on the 4-10-0 treatment expressed as a percentage of those on the 4-10-10, were + 0.356 for exchangeable potassium, + 0.466 for potassium soluble in sodium acetate, and + 0.444 for potassium extracted by the Neubauer method. Each correlation coefficient was significant at the 1 per cent level. As calculated from the mean values presented in Table 1, the alfalfa yields on the 4-10-0 treatment expressed as a percentage of those on the 4-10-10 treatment were highest for the Carp, North Gower and Rideau soils, and lowest for the Uplands and Rubicon soils. Table 5 shows that, for each of the three methods used, the soil test values for the Carp, North Gower and Rideau soils were relatively high as compared with those obtained for the Uplands and Rubicon soils.

The uptake of potassium by oats and alfalfa on the 4-10-0 treatment, expressed as a percentage of the uptake on the 4-10-10, was used as a basis

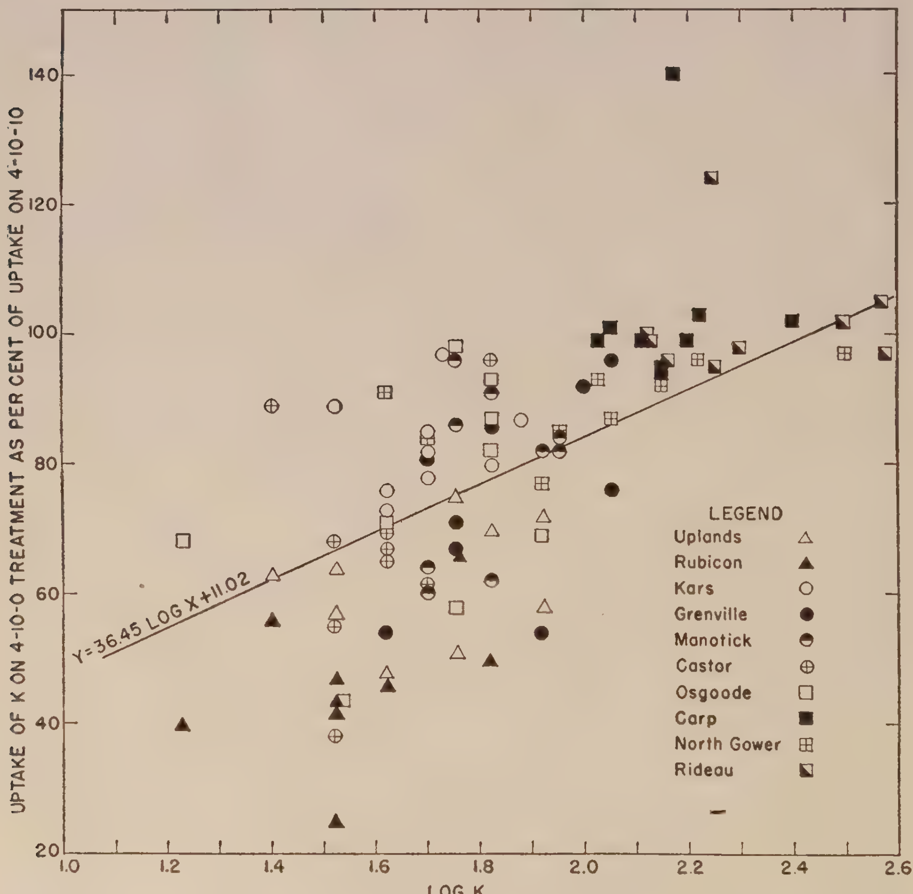

FIGURE 3. Relationship between exchangeable K in soils and greenhouse results.

TABLE 6.—RELATIONSHIP OF SOIL POTASSIUM VALUES AND UPTAKE OF POTASSIUM BY THE CROPS ON THE 4-10-0 TREATMENT EXPRESSED AS A PERCENTAGE OF THE UPTAKE ON 4-10-10

Soil type	Exchangeable		Peech and English		Neubauer	
	D.F.	Correlation coefficient	D.F.	Correlation coefficient	D.F.	Correlation coefficient
Uplands sand	6	+ 0.302	6	+ 0.096	3	+ 0.305
Rubicon loamy sand	7	+ 0.461	7	+ 0.735*	4	− 0.062
Kars gravelly sandy loam	7	+ 0.260	7	− 0.108	4	− 0.326
Grenville loam	7	+ 0.524	7	+ 0.565	4	+ 0.629
Manotick sandy loam	7	+ 0.353	7	+ 0.278	4	+ 0.964**
Castor silt loam	6	+ 0.402	6	+ 0.283	3	+ 0.810
Osgoode loam	7	+ 0.451	7	+ 0.472	4	+ 0.821*
Carp clay loam	7	+ 0.062	7	− 0.150	4	+ 0.026
North Gower clay loam	7	+ 0.629	7	+ 0.268	4	+ 0.315
Rideau clay	6	+ 0.127	6	+ 0.149	4	+ 0.657
All soil types	85	+ 0.619**	85	+ 0.618**	56	+ 0.754**

* Significant at 0.05.
** Significant at 0.01.

for appraising, in more detail, the three methods employed in estimating 'available' soil potassium. Because of certain conditions in the experiment, the uptake of potassium by both crops was considered to provide a better basis than yield response for appraising the soil test values. These conditions were the lack of yield response by the oat crop on most of the soils, luxury consumption of potassium by the oats, and the competition of oats and alfalfa for the relatively small amounts of potassium applied.

The relationships between the values for potassium uptake and the amounts of potassium extracted from the soil samples by Neubauer's method, by the method of Peech and English and by using a neutral, normal solution of ammonium acetate as the extractant, are shown in Figures 1, 2 and 3†, respectively.

Correlation coefficients showing the relationship between soil potassium values and those for uptake of potassium are presented in Table 6. The correlation coefficients calculated on the basis of individual soil types reached significance in only three cases. However. the evaluation of the methods on this basis was limited because of the few samples available. When the correlation coefficients were computed without regard to soil type, the values obtained were highly significant irrespective of the method used in determining the 'available' potassium content of the soil. The fact that the Neubauer method showed the highest correlation might be expected since it is a biological procedure.

† For the sake of brevity, the different soils are identified in the graphs by the soil series name.

Although the results obtained by each of the three methods used were correlated with those for uptake of potassium, it is evident from Figures 1, 2 and 3 that the values for the individual soil samples deviate considerably from the line that best fits the data.

REFERENCES

1. Atkinson, H. J., G. R. Giles, and A. J. MacLean. Fertility studies on soil types: II. The physical and chemical composition of soils from Carleton and Grenville Counties in Ontario. Can. J. Agr. Sci. 33 : 116-124. 1953.
2. Garman, W. H. Photronic method for determining potassium in soils and plants. Soil Sci. 56 : 101-107. 1943.
3. Hills, G. A., N. R. Richards, and F. F. Morwick. Soil Survey of Carleton County. Report No. 7, Ontario Soil Survey, Guelph, Ont. 1944.
4. MacLean, A. J., R. F. Bishop, and L. E. Lutwick. Fertility studies on soil types: III. Phosphorus supply and requirement as shown by greenhouse studies and laboratory tests. Can. J. Agr. Sci. 33 : 330-343. 1953.
5. Peech, M., and L. English. Rapid micro-chemical soil tests. Soil Sci. 57 : 167-195. 1944.
6. Richards, N. R., B. C. Matthews, and F. F. Morwick. Soil Survey of Grenville County. Report No. 12, Ontario Soil Survey, Guelph, Ont. 1949.
7. Wright, L. E., *et al.* Chemical methods of soil analysis. Div. of Chemistry, Science Service, Canada Dept. of Agriculture, Ottawa. 1949.

EXPERIMENTS ON CONTROL OF THE ONION MAGGOT, *HYLEMYA ANTIQUA* (MEIG.), IN THE INTERIOR OF BRITISH COLUMBIA[1]

D. G. FINLAYSON AND R. H. HANDFORD[2]

Field Crop Insect Section, Entomology Laboratory, Kamloops, B.C.

[Received for publication October 14, 1953]

ABSTRACT

Experiments were conducted in two localities in the interior of British Columbia in 1951 to find a more effective and less expensive material than calomel for controlling the onion maggot. A seed treatment with DDT, 50 per cent wettable powder, was the most practical substitute. Lindane, 25 per cent wettable powder, applied to the soil surface at 10-day intervals, was significantly better than DDT for seedling emergence and yield of marketable onions and not significantly poorer for preventing maggot damage. However, it is more expensive in materials and in the labour of application. Seed treatments with very low rates of aldrin and dieldrin wettable powder showed promise. Emulsions of aldrin, chlordane, dieldrin, and DDT, poured into the seed furrow ahead of the seed, drastically reduced germination and yield.

INTRODUCTION

The onion maggot, *Hylemya antiqua* (Meig.), has been a serious pest of onion crops in the interior of British Columbia for more than 25 years. After an unusually heavy infestation in 1927, Vroom* investigated the life-history and control of the maggot. He obtained satisfactory protection from maggot damage by the use of mercuric chloride or oil-bordeaux emulsion. Treatment of seed with mercurous chloride (calomel) subsequently became the accepted method of control [(Glasgow (2)] and was used extensively until 1950 in the interior of British Columbia.

In 1948, severe infestations of the onion maggot were not satisfactorily controlled by the calomel seed treatment; heavy losses occurred in untreated crops of onions. This, coupled with the high cost of mercurous chloride, led the authors to test various organic insecticides. Preliminary experiments in 1950 at Vernon and Kelowna supplied valuable information for more detailed investigations at the same locations the following year.

MATERIALS AND METHODS

The methods used in the experiments were adapted from those used by McLeod (3).

The plots at both sites were arranged in randomized blocks, replicated four times. Each plot had 5 rows, 25 feet long, with 16 inches between rows, the outside rows serving as buffers.

All seeding was done with a rod-row multiple-gear seeder. The variety Yellow Globe Danvers was used.

---

[1] Contribution No. 3124, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Assistant Entomologist and Officer-in-Charge.

* Vroom, P. Onion root maggot. Life history and control experiments. *In* Annual report of the Field Crop Insect Laboratory, Vernon, British Columbia, 1928. *Unpublished.*

TABLE 1.—POUNDS OF TOXICANT PER ACRE AND AVERAGE NUMBERS OF SEEDLINGS EMERGING, AVERAGE PERCENTAGES OF THESE DAMAGED, AND AVERAGE YIELDS IN POUNDS OF ONIONS PER THREE CENTRAL ROWS PER PLOT FOR VARIOUS TREATMENTS AGAINST THE ONION MAGGOT AT KELOWNA AND VERNON, B.C., 1951[1]

Treatment	Kelowna				Vernon			
	Toxicant, lb.	Seedlings	Damage	Yield	Toxicant, lb.	Seedlings	Damage	Yield
Seed—								
Aldrin, 50%[2]	0.05	298	17.6	25.7	—	—	—	—
Calomel[4]	5.0	227	11.0	24.0	5.0	180	17.7	7.0
DDT, 50%[5]	2.5	148	0.3	19.5	—	—	—	—
DDT, 97%[7]	—	—	—	—	2.4	385	2.1	10.7
Dieldrin, 50%[2]	—	—	—	—	0.05	346	38.1	11.7
Furrow[11]—								
Aldrin, 23%[3]	0.5	27	0.0	5.7	0.5	37	4.1	1.2
Chlordane, 65%[8]	—	—	—	—	2.0	21	2.4	1.5
DDT, 25%[6]	—	—	—	—	2.0	30	16.5	2.5
Dieldrin, 18.5%[3]	0.5	37	1.7	7.5	—	—	—	—
Parathion, 1.0%[9]	—	—	—	—	1.0	150	7.8	6.7
Surface[12]—								
Lindane, 25%[10]	3.0	275	4.7	41.5	—	—	—	—
Check—								
Untreated I (damaged onions not removed)[13]	—	151	24.4	13.5	—	354	79.3	2.7
Untreated II (damaged onions removed)[13]	—	191	27.2	15.2	—	—	—	—
Difference necessary for significance at 5% level	—	113	8.5	11.1	—	95	6.8	6.2

[1] Rate of seeding per acre: 5 lb.
[2] Wettable powder and [3] emulsifiable concentrate—Julius Hyman & Co., Denver 1, Colo.
[4] Technical powder, [5] wettable powder, [6] emulsifiable concentrate, and [9] dust—Ansell Laboratories, Vernon, B.C.
[7] Wettable powder—Pennsylvania Salt Manufacturing Co. of Washington, Tacoma, Wash.
[8] Emulsifiable concentrate—Velsicol Corp., Chicago, Ill.
[10] Wettable powder—Dow Chemical of Canada Ltd., Toronto, Ont.
[11] Emulsions applied with 260 gal. of water per acre.
[12] Applied with 780 gal. of water per acre.
[13] See "Methods".

Eight treatments were applied at each site. The insecticides used were: aldrin, calomel, chlordane, DDT, dieldrin, lindane, and parathion. Table 1 gives the formulations and methods and rates of application of the insecticides.

Three methods of application were used. For the *seed treatment*, the onion seeds were moistened with water and mixed with a specific amount of chemical until it adhered uniformly to the seed; aldrin, calomel, DDT, and dieldrin were used in this way. For the *furrow treatment*, the insecticides were applied as emulsions immediately ahead of the seed or as a dust with the seed. The soil covered both seed and chemical. Aldrin, chlordane, DDT, and dieldrin were applied as emulsions and parathion as a dust. For the *surface treatment*, the insecticide, lindane, was mixed with water and applied to the seedlings and the soil surface. Three applications were made, the first when 50 per cent of the seedlings were in the loop stage (i.e., just before the tip of the cotyledon became free of the ground), and the second and third at 10-day intervals.

Phytotoxic effects of the treatments on the seedlings were measured by counting the plants when they emerged. Maggot damage was measured by counting the plants killed by maggots after emergence and until harvest. The combination of these and possibly other factors was measured by weighing the marketable onions. Normal thinning reduced the differences between yields. All records were made in the 3 central rows of each plot.

Maggot damage was appraised twice weekly, beginning as soon as damage was observed. The damaged plants, identified by the wilting leaves, were pulled, the cause of damage determined, and the plants replaced in or close to their original positions in the row. Thus the maggots could inflict a degree of damage approximating what would have occurred if the damaged onions had not been pulled for examination. At Kelowna, in a second series of check plots (Untreated II, Table 1), the maggot-damaged plants were removed from the rows and placed midway between rows to determine if this removal reduced maggot damage.

Data for emergence, damage, and yield were analysed by analysis of variance.

RESULTS AND DISCUSSION

There were significant differences at both locations between numbers of emergent seedlings, percentages of maggot damage, and yields of marketable onions (Table 1) resulting from the various treatments.

Seed Treatments

The seed treated with DDT, 97 per cent wettable powder, produced significantly more seedlings than the seed treated with calomel and the plants sustained significantly less maggot damage, but the yield of marketable onions was not significantly higher. The seed treated with DDT, 50 per cent wettable powder, did not differ significantly from that treated with calomel in numbers of seedlings or in yield, but damage by maggots was significantly less. In the preliminary tests at Vernon and Kelowna in 1950 there was no significant difference between the 50 per cent wettable DDT and the calomel seed treatments for any of the three criteria. Growers who followed the tentative recommendations based on the 1950 results

experienced some difficulty obtaining a uniform flow of the treated seed through the seeder, but they agreed unanimously that the lower cost of material and the added protection against maggot damage justified the additional attention required. DDT cost $2.30 less per pound of seed than calomel, or $11.50 per acre, at the customary seeding rate of 5 pounds per acre.

Fifty per cent wettable aldrin or dieldrin applied to the seed in extremely small quantities (1 : 100 by weight) did not give satisfactory protection from maggot attacks. However, each was among the best treatments and significantly better than the remainder, at its site, both for number of emergent seedlings and, except lindane, for yield. Both appear very promising but require further testing at higher dosages.

Furrow Treatments

Emulsions in most instances gave excellent protection against maggot damage but affected emergence so adversely that yields were very low. This was true irrespective of the insecticides used, suggesting that the solvent, or solvents, may have been the cause.

The 1 per cent parathion dust gave satisfactory protection against maggot damage but the number of seedlings produced was significantly lower than that of the untreated check.

A proprietary dust, Vitomag* containing DDT, used as a furrow treatment in 1950, produced yield and damage data that were not consistently satisfactory; the expense made the treatment uneconomical.

Surface Treatments

Plots treated with lindane produce significantly higher yields than those treated in any other way; maggot damage was satisfactorily reduced and seedling emergence was high. However, the cost was greater for materials and for labour of application. Moreover, there were indications in the 1950 experiments that emergence of seedlings might be affected adversely under some conditions; McLeod (3, 4) noted that hexachlorocyclohexane applied to the seed or soil was phytotoxic, and Finlayson (1) reported that lindane applied to the seed gave similar effects. The possibility that the added moisture used with this application (Table 1) was responsible for the higher germination and better yield has yet to be investigated.

Oil-bordeaux emulsion, three surface applications to onions grown from calomel-treated seed, was one of the more effective treatments in 1950. However, it was not sufficiently better than calomel alone, or the 50 per cent wettable DDT, to justify the extra cost of labour and materials.

REFERENCES

1. Finlayson, D. G. The effect of certain insecticides on the germination and growth of onions. II. Insecticides applied to the seed. Proc. Ent. Soc. British Columbia 48 : 70-76. 1952.
2. Glasgow, H. Seed treatments for control of root maggots. J. Econ. Ent. 27 : 303-308. 1934.
3. McLeod, W. S. Hexachlorocyclohexane in the control of onion maggot. J. Econ. Ent. 39 : 631-637. 1946.
4. McLeod, W. S. Effect of hexachlorocyclohexane on onion seedlings. J. Econ. Ent. 39 : 815. 1946.

* Vitox Limited, Burscough Bridge, Ormskirk, England.

THE EFFECTS OF 2,4-D SPRAY DRIFT ON SWEET CLOVER PLANTS IN THE SECOND YEAR OF GROWTH

J. E. R. Greenshields and W. J. White

Forage Crops Laboratory, Saskatoon, Sask.

[Received for publication December 3, 1953]

ABSTRACT

The effects of drift spray of 2,4-D butyl ester at 6 ounces per acre were sublethal but resulted in shedding of leaves, distortion of leaves and stems, and shedding of flowers. Effects decreased with distance but were clearly discernible at 96 rods. Fifty-one days after treatment the seed yield per plot in grams was 25.1 for the check, 2.3 for plants adjacent to and 18.9 for plants 96 rods from the sprayed area. Seed quality decreased with proximity to the sprayed area. In a supplementary test residual 2,4-D in spraying equipment reduced seed yield 50 per cent. Low seed yields in recent years may be attributed in part at least to the above demonstrated effects.

For the past several years in various localities in Saskatchewan farmers have complained of low seed yields of sweet clover in spite of apparent good weather conditions and adequate bee populations. It has also been observed that the seed set in the experimental plots at Dominion Forage Crops Laboratory at Saskatoon in recent years has been late and very light. 2,4-D drift spray was suspected of affecting the plants resulting in partial sterility, and delayed seed setting. Therefore an experiment was designed to test the effect of 2,4-D drift spray on sweet clover that was flowering. Since no pertinent literature on this subject was available to the authors a review of related literature has been omitted.

MATERIAL AND METHODS

From a seeding made in 1952 approximately 250 plants of the variety Arctic were dug out of the field early in the spring of 1953. Each plant was placed in a 7-inch pot. The plants withstood transplanting very well and were tied up to looped No. 9 wire to prevent breaking over. The potted plants were located outside a greenhouse before and after treatment.

On July 23, 1953 all the plants were taken to a large field of summer-fallow on the University farm and arranged in five replicates with 5 plants per treatment in each replicate. The distance between replicates was 2 rods. There were seven treatments: Treatment 1 was the check and the 25 plants were returned to the greenhouse location before the spraying commenced. The plants in Treatment 2 were placed at right angles to the wind, as close as possible to the area to be sprayed, but with sufficient distance that no direct spray from the machine would hit the pots or plants. Plants in Treatments 3, 4, 5, 6 and 7 were located 4, 12, 24, 48 and 96 rods, respectively from the area to be sprayed and parallel to those in Treatment 2. Spraying was carried out commencing immediately adjacent and

[1] Contribution from Division of Forage Crops, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada.
[2] Agricultural Scientist, Forage Crops Laboratory, Saskatoon.
[3] Officer-in-Charge, Forage Crops Laboratory, Saskatoon.

parallel to Treatment 2, working away from the material. A conventional type of boom-sprayer was used, delivering 5 gallons of water per acre at 6 ounces of acid equivalent of 2,4-D butyl ester per acre. Spraying commenced at 9.00 a.m. and continued for one hour; the wind velocity dropped from 17 m.p.h. to 13 m.p.h. during the time of spraying.

In order to get an idea of the concentration of 2,4-D required to affect sweet clover plants a small push-type experimental plot sprayer was used to treat another group of plants. Working in a large shed, four plants were sprayed at each of the following rates: water only, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, 1 and 2 ounces of 2,4-D butyl ester acid equivalent per acre. These plants were then returned to their location outside the greenhouse.

EXPERIMENTAL RESULTS

Within approximately 10 days after spraying distinct differences were apparent between the treated groups of plants. On the 18th and 51st day after treatment records were taken on various characteristics. Table 1 presents a summary of these observations.

TABLE 1.—GENERAL CONDITION OF THE PLANTS 18 AND 51 DAYS AFTER TREATMENT

Treatment number and distance from sprayed area	18 days after treatment			51 days after treatment			
	Leafiness score*	Bloom score*	Distortion of leaves and stem score*	Estimated days later than the check	Leafiness score*	Flowering score*	Estimated per cent of seed ripe
1 – Check	1	1	1	0	9	10	55
2 – adjacent	7	10	10	30	2	2	1
3 – 4 rods	6	7	5	20	5	6	5
4 – 12 rods	4	6	5	15	6	5	10
5 – 24 rods	5	4	2	10	7	8	25
6 – 48 rods	5	4	3	8	8	9	35
7 – 96 rods	2	3	2	5	9	9	45

* Basis of scoring—
— *Leafiness:* 1 = leaves of normal abundance; 10 = no leaves present.
— *Bloom* 1 = flowers completely open; 10 = no flowers open.
— *Distortion* 1 = no curling of ends of leaves and stems; 10 = severe curling of leaves and stems.
— *Flowering* 1 = full flowering with no seed set; 10 = flowering completed with seed set.

When the seed on the check appeared to be ready to harvest the plants were cut and the amount of seed was recorded on a per plot basis. The seed weights and summary of the analysis are given in Table 2.

Material sprayed with a hand sprayer in the shed indicated that even a sprayer that had been thoroughly washed out with water still had sufficient residual 2,4-D present to cause some damage. The seed yield of plants sprayed with water averaged about 11 gm. per plot which approximates the effect of 2,4-D drift on Treatments 3 and 4. The seed yield of the plants treated at $\frac{1}{4}$ ounce of 2,4-D per acre averaged 2 gm. per plot being equal to Treatment 2, which was adjacent to the field sprayed. At treatments of $\frac{1}{2}$ ounce or greater there was no seed set and distortion of stems was progressively more pronounced up to the highest rate of 2 ounces per

TABLE 2.—SUMMARY OF ANALYSIS OF VARIANCE OF SEED WEIGHTS IN GRAMS PER PLOT OF THE PLANTS HARVESTED SEPTEMBER 17, 1953

Treatments	1	2	3	4	5	6	7
Rep. 1	22.9	1.1	10.0	10.1	19.5	16.4	20.9
Rep. 2	22.8	1.9	13.3	10.8	25.5	6.6	17.8
Rep. 3	26.7	2.9	5.9	8.3	14.5	23.0	19.4
Rep. 4	28.5	1.5	5.7	12.2	13.1	16.4	21.5
Rep. 5	24.4	4.1	11.7	7.6	12.3	23.4	14.8
Average	25.1	2.3	9.3	9.8	17.0	17.2	18.9

L.S.D. at 0.05 level of significance—5.46.
L.S.D. at 0.01 level of significance—7.25.

acre. In all cases the dose was sub-lethal; however, at the ½-, ¾-, 1- and 2-ounce rates of application the plants did not recover sufficiently to flower before the end of the season.

DISCUSSION

2,4-D drift spray resulted in shedding of leaves, distortion of leaves and stems, and shedding of the flowers (Table 1). These effects were greatest on those plants adjacent to the sprayed area and decreased with distance. Even at 96 rods, however, injury was clearly discernible. The effects were sub-lethal in all cases and the plants recovered with time. The primary ultimate effect was a delay in maturity of the seed crop. When harvested for seed about two months after treatment, the adverse effects of the drift spray were very evident in the seed yields (Table 2). The yield of seed does not reveal the complete picture, however. A considerable proportion of the seed from the more severely affected plants was green and shrivelled. Seed quality improved with distance from the sprayed area but even at 96 rods was inferior to the check.

In the normal course of events in Saskatchewan sweet clover would begin blossoming from mid-June to the end of the month. A damaging frost can be expected from early September onward. A minimum of 30 to 35 days is required from flowering to seed maturity. Flowering proceeds over a few weeks, increasing up to a peak of full bloom and then declining. For maximum yields and good seed quality the full bloom stage must occur considerably before early August. Flowers pollinated after that date cannot be depended upon to mature. Spraying of cereal crops is usually done from early to mid-June. On sweet clover fields adjacent to cereal crops drift spray from such treatments could obviously delay the attainment of full flower beyond the optimum or latest date permissible for attainment of high yields of good quality seed. It should be noted here that the plants in this experiment were two or three weeks later than plants growing in the field, due to the setback received from being transplanted. When sprayed on July 23, 1953, these plants showed about 25 per cent bloom, approximately equal in amount of flowering to plants in the field about the last week in June.

It should be noted that 2,4-D drift in many farmers' fields may be even more severe than in the experiment reported. In many instances the area sprayed would be wider in relation to the sweet clover field than in the experimental study. There could thus be a longer period of exposure to the drift spray. Furthermore, spraying may be done at wind velocities in excess of those experienced in this study. The variability in seed yields shown in Table 2 for Treatment 6 suggests that under certain conditions the severe adverse effects may extend beyond the limits indicated by the averages obtained.

2,4-D sprayers are often used to apply DDT to seed fields for control of sweet clover weevil. That residual 2,4-D in the spraying equipment may have an adverse affect on seed yields is indicated in data presented above. The combined effect of residual 2,4-D material in the spray equipment and of drift spray from adjoining fields would probably be particularly detrimental.

ACKNOWLEDGMENT

Appreciation is expressed to D. W. Staniforth of Iowa State College, Ames, Iowa, for assistance in designing the experiment.

THE INFLUENCE OF VARIETY AND PREDISPOSING FACTORS ON THE OCCURRENCE OF YELLOW BERRY (STARCHINESS) IN WHEAT[1]

B. J. SALLANS[2] AND P. M. SIMMONDS[3]

Plant Pathology Laboratory, Saskatoon, Sask.

[Received for publication January 22, 1954]

ABSTRACT

Greenhouse experiments have shown that yellow berry or piebald in wheat was increased by the addition of monobasic potassium phosphate to the soil. On the other hand, the addition of sodium nitrate reduced the incidence of yellow berry thus lending support to the findings of other authors that a shortage of nitrates in the soil may be the main cause of the condition. Plants which were inoculated with *Pythium arrhenomanes* Drechsl. had much lower percentages of yellow berry than uninoculated plants. Lowering the moisture level of the soil also reduced the incidence of yellow berry. Evidence is presented to show that factors which increase yields of grain tend to increase the percentages of yellow berry by increasing carbohydrates in relation to proteins. Those conditions tending to decrease yields, on the other hand, reduce percentages of yellow berry by reducing carbohydrates in relation to proteins. The exception to this general rule is the increase in yield resulting from nitrogen-containing fertilizer which is accompanied by reduced percentages of yellow berry. Greenhouse methods to test the inherent tendency of wheat varieties to yellow berry indicate that Garnet and Regent are not readily affected; Red Bobs, Marquis and Mindum become affected quite readily under favourable conditions and Thatcher is intermediate in reaction.

INTRODUCTION

The physiological condition in hard wheats known to pathologists as yellow berry received much attention during the first two or three decades of this century in the United States and Canada. It has been referred to as piebald, mealiness or starchiness. Plant breeders (1, 13) in describing kernel texture have distinguished between vitreous and starchy kernels and such intermediate classes as semi-vitreous and semi-starch. The names yellow berry or starchiness will be used in this paper except where a distinction is to be made between completely starchy and partly starchy kernels. Partly starchy kernels will be referred to as piebald.

Yellow berry is evident in threshed grain. It occurs in normally hard vitreous wheats as opaque, soft kernels. Colour depends on the colour of the testa and varies from very pale yellow to a light yellow. Cross sections of the endosperms may be completely white and starchy in texture, or in piebald kernels may be partly starchy and partly vitreous in sharply defined areas.

In view of the data to be presented in this paper a brief review of conditions described by various authors as influencing the appearance of yellow berry in wheat seems desirable. Increases in starchiness have been reported to have resulted from applications of potassium (6). Partial or complete control of yellow berry in wheat with nitrate fertilizers has been reported by Jones and Mitchell (8) and by Headden (6). A long post-floral period and late maturity (3) resulted in starchiness in wheat kernels.

[1] Contribution No. 1355 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa.
[2] Senior Plant Pathologist.
[3] Officer in Charge.

Similarly late ploughing in the summerfallow year (6) and growing wheat on podsolized soils (1) increased percentages of starchy kernels. On the other hand, decreases in starchiness have been reported as caused by a short post-floral period, early maturity (3, 12), and high temperatures three weeks before maturity. Minz (10) reported yellow berry in kernels of wheat plants that were infected by the stem rust organism, while little or none was present in plants where rust was controlled by dusting with sulphur. Caldwell *et al.* (5) reported an increase of piebald and starchy kernels in plants infected by the leaf rust organism over plants with little or no leaf rust. A review of literature made by Aamodt and Torrie (2) brings together considerable evidence that kernel texture is heritable, though the important role of environmental factors led some of the earlier authors to suggest that the tendency to yellow berry is not an inherited character.

A number of authors (see Table 1) have published data which indicate a close correlation between protein content and kernel texture. Samples of wheat with high proportions of yellow berry or piebald have lower percentages of protein than unaffected samples. Thus yellow berry in hard bread wheats is an indication of poor quality. With the introduction of chemical and baking methods of determining quantity and quality of protein in wheat, visible starchiness appears to have little place as a measure of quality in the grain trade. The high standards which new varieties must attain in regard to quality as indicated by chemical and baking tests before they are licensed for distribution to growers, appear to have resulted in a marked reduction of yellow berry in commercial wheat. There is, nevertheless, a considerable area in the Canadian Prairies along the northern fringes of the wheat growing plains where low-protein wheats are produced and where starchiness occurs regularly. Since this low-protein wheat forms a relatively small proportion of the total crop, yellow berry may have little influence ordinarily in the export trade.

Table 1.—Percentages of protein reported by various authors in samples of wheat classified on the basis of kernel texture

	Kernel Texture			
	Normal (vitreous)	Piebald		Yellow berry (starchy)
		Semi-vitreous	Semi-starchy	
Shutt 1905 (14)	12.63	—	—	9.93
Shutt 1906 (14)	13.52	—	—	10.01
Caldwell *et al.* (5)*	—	12.00	10.15	—
	—	10.58	10.19	—
Aamodt and Torrie (2)	13.0	11.0	9.4	9.2
Shollenberger and Coleman (13)	10.7–14.4	—	—	7.5–9.9
Anderson and Aitken (4)	13.0	10.7		9.6

* Samples were fitted into kernel texture classes on the basis of percentages of vitreous, piebald and starchy kernels given for each sample.

There appears, however, to be a progressive decline of nitrogen in the soil as cultivation is continued. Mitchell, Moss and Clayton (11) reported losses from 9 to 43 per cent of nitrogen in cultivated soils compared to uncultivated soils. Initial losses appear to be large during the first few years after breaking. Subsequently there may be a very slow rate of loss of nitrogen. It is conceivable, therefore, that in years of adequate water supply the grain over increasing proportions of the wheat growing plains will be low in protein and starchy in appearance. A survey in 1952, described in the next section, lends support to this view.

INCIDENCE OF YELLOW BERRY IN 1952

Conditions in Saskatchewan in 1952, when wheat yields were 60 to 70 per cent above the long-time average, were believed to be conducive to yellow berry. A survey was made for this condition in 88 random samples of wheat collected independently by 11 agriculturists in 11 representative areas of the province. These samples were examined carefully for starchiness of the endosperm. Though partial and complete starchiness were recorded separately the two sets of data were added for presentation in Table 2. Two samples were rejected from the data as they were weathered to such an extent that true yellow berry was obscured by starchiness caused by soaking and drying.

Two of the 88 samples proved to be entirely free of yellow berry, and 57 samples had 10 per cent or more of the kernels affected. The first six locations are in the open-plains region of the province and in an average

Table 2.—The percentages of kernels of wheat showing partial or complete starchiness of the endosperm (yellow berry)

Location	Sample number								Mean
	1	2	3	4	5	6	7	8	
Maple Creek	21	9	18	25	26	19	19	58	26
Kerrobert	9	11	6	9	11	6	8	13	9
Elbow	10	9	5	29	21	15	22	42	19
Weyburn	9	16	39	28	8	37	6	9	19
Davidson	15	7	3	4	2	13	11	3	7
Tessier	0	15	7	8	13	1	3	0	6
Yorkton	15	12	8	8	51	15	73	46	28
Wynyard	21	26	44	17	28	27	9	38	26
Shellbrook	9	23	14	32	—	9	—	6	15
Nipawin	91	5	27	32	50	60	72	64	50
Moosomin	32	19	31	45	39	38	25	56	36
Mean of all samples	—	—	—	—	—	—	—	—	22

crop year would be virtually free of yellow berry. The remaining five places, on the other hand, are located in the semi-wooded or wooded areas of the province and would ordinarily have much less yellow berry in the samples of grain. Nevertheless these data demonstrate that such high quality wheats as are now grown in Saskatchewan may show yellow berry when crop yields are high or growth conditions are favourable to its appearance.

The average protein content of the 1952 wheat crop in Western Canada has been reported by the Board of Grain Commissioners as 12.7 per cent. This compares with a long-time average protein content of 13.6 per cent. Published data, which are summarized in Table 1, indicate that when protein content of wheat falls below about 12 per cent, piebald or semi-starchy kernels are likely to appear and increase with progressively lower levels of protein. Completely yellow berry kernels are likely to occur at protein levels of 10 per cent or lower. On the basis of these data it is not surprising that considerable yellow berry should be present in the 1952 crop with an average protein content of 12.7 per cent.

In view of the probability that yellow berry will become more of a problem as soil nitrogen levels decline the present paper will present the results of some greenhouse experiments on root diseases in which yellow berry appeared as a result of some of the treatments.

EXPERIMENTAL EVIDENCE OF SOME FACTORS FAVOURING DEVELOPMENT OF YELLOW BERRY

A greenhouse test, designed to measure the influence of various treatments on the recovery of wheat plants which were inoculated with *Pythium arrhenomanes* Drechsl. gave some information on yellow berry. A factorial design was used, there being four factors at two levels each, giving 16 treatment combinations which were replicated four times. The factors were: soil moisture levels adjusted frequently to 45 per cent and 60 per cent of the moisture-holding capacity; nitrogen added to the soil in the form of $NaNO_3$ at the rate of 0.75 grams per one-gallon crock as compared with no added nitrogen; phosphorus and potassium were added to the soil as KH_2PO_4 at 0.5 grams per crock as compared with no added P or K; and no inoculation versus inoculation of the soil with 45 grams per crock of a cornmeal-soil culture of *P. arrhenomanes*. The soil for the test was steam sterilized for three hours at 15 lb. pressure. The inoculum was mixed into one-half inch of soil just below seed level. Twenty-eight seeds of Marquis wheat were planted per crock and uniform stands of 22 plants per crock were obtained by removing plants at random. The moisture level of the soil was kept at 50 per cent of the moisture-holding capacity for one month until the plants were in the fourth-leaf stage, when moistures were adjusted to the required 45 per cent and 60 per cent levels. At the same time, the fertilizers were added in water solutions poured over the surfaces of the soil. The applications of the salts approximated rates of 200 and 300 pounds per acre of KH_2PO_4 and $NaNO_3$, respectively.

It was noted in harvesting the grain from this test that wide variations in the percentages of yellow berry kernels were associated with the various treatments. Tables 3 and 5 give the percentages of kernels showing the

TABLE 3.—PERCENTAGES OF KERNELS SHOWING THE YELLOW BERRY CONDITION AS INFLUENCED BY THE ADDITION OF KH_2PO_4 AND $NaNO_3$ TO THE SOIL

Treatments	No KH_2PO_4	KH_2PO_4	Means
No $NaNO_3$	25.0	54.2	39.6
$NaNO_3$	13.9	22.5	18.2
Means	19.5	38.3	28.9

N.B. Differences between treatment means and the interaction $NaNO_3 \times KH_2PO_4$ are all highly significant as found on analysis of variance of the data after transformation to angles.

TABLE 4.—YIELDS OF GRAIN, GRAMS PER CROCK, AS INFLUENCED BY THE ADDITION OF KH_2PO_4 AND $NaNO_3$ TO THE SOIL

Treatments	No KH_2PO_4	KH_2PO_4	Means
No $NaNO_3$	8.68	9.80	9.24
$NaNO_3$	8.90	11.52	10.21
Means	8.79	10.66	9.72

Necessary difference at the 1 per cent level between means is 0.78 grams, and between values in the body of the table is 1.11.

yellow berry condition as influenced by the various factors of the experiment.

The addition of the salt KH_2PO_4 had the effect of increasing the percentages of yellow berry kernels from 19.5 to 38.3. The addition of potassium to the soil has been reported (6) to increase yellow berry in wheat. The authors have not found a reference in literature to a similar effect by phosphorus. Since, however, Saskatchewan soils are not deficient in potassium and many are deficient in available phosphates, it appears probable that the phosphorus in the fertilizer was responsible for the increase in yellow berry. This probability is strengthened by the evidence given below that a strong correlation exists between percentage of yellow berry and yield of grain, in view of the fact that increased yields follow use of phosphate fertilizers in many Saskatchewan soils. The application of nitrogen as $NaNO_3$ reduced yellow berry percentages from 39.6 to 18.2. This may be expected in view of the evidence discussed below that yellow berry results from nitrogen deficiency and a consequently lower percentage of protein in the grain.

Yields of grain were significantly increased by the addition of a phosphate fertilizer, Table 4, and by nitrate in the presence of phosphatic fertilizer. Comparing these data with those of Table .3 an increase in yield caused by the fertilizer KH_2PO_4 is associated with an increase in yellow berry kernels. On the other hand, an increase in yield, which resulted from the use of a nitrate, was associated with a decrease in percentage of yellow berry kernels.

TABLE 5.—PERCENTAGES OF KERNELS SHOWING THE YELLOW BERRY CONDITION AS INFLUENCED BY INOCULATION WITH *P. arrhenomanes* AND LEVELS OF THE MOISTURE HOLDING CAPACITY (MHC) OF THE SOIL

Treatments	Soil moisture levels		Means
	45% MHC	60% MHC	
No *P. arrhenomanes*	15.8	79.0	47.4
P. arrhenomanes	1.2	19.6	10.4
Means	8.5	49.3	28.9

N.B. Differences between treatment means and the interaction, moisture levels × *P. arrhenomanes*, are all highly significant as indicated by analysis of variance applied to the data after transformation to angles.

TABLE 6.—YIELDS OF GRAIN, GRAMS PER CROCK, AS INFLUENCED BY INOCULATION WITH *Pythium arrhenomanes* AND BY LOW VERSUS OPTIMUM LEVELS OF SOIL MOISTURE

Treatments	Soil moisture levels		Means
	45% MHC	60% MHC	
No *P. arrhenomanes*	8.60	11.54	10.07
P. arrhenomanes	7.90	10.84	9.37
Means	8.25	11.19	9.72

Necessary differences at the 1 and 5 per cent levels between means are 0.78 grams and 0.58 grams, an between values in the body of the table are 1.11 and 0.83 grams, respectively.

Table 5 indicates that low soil moisture is not conducive to yellow berry while an optimum soil moisture level of 60 per cent MHC favours its development. Plants infected with *P. arrhenomanes* had much lower percentages of yellow berry than had the uninoculated plants. The interaction between disease and moisture level proved highly significant statistically. This indicates that the tendency for yellow berry to develop at optimum or high soil moistures is reduced to a considerable degree when the plants are attacked by *P. arrhenomanes*.

Table 6 shows that *P. arrhenomanes* reduced yields moderately, while low soil moisture caused considerable reduction in yield. Comparing Tables 5 and 6 there is a considerable degree of correlation between yield and percentage of yellow berry kernels. This was noted also in the case of the fertilizer KH_2PO_4 (Tables 3 and 4). This suggests that the primary influence of these three treatments is on growth of plants and their final yields of grain and that yellow berry is a deficiency disease which shows up more severely as total yields of grain are increased. The influence of added nitrogen, on the other hand, is to reduce yellow berry even though some increase in yield may be present, as in Tables 3 and 4. It may be concluded from these facts that yellow berry develops when for any reason nitrogen becomes the limiting factor in plant development. This conclusion is supported by findings of other authors reviewed in this paper.

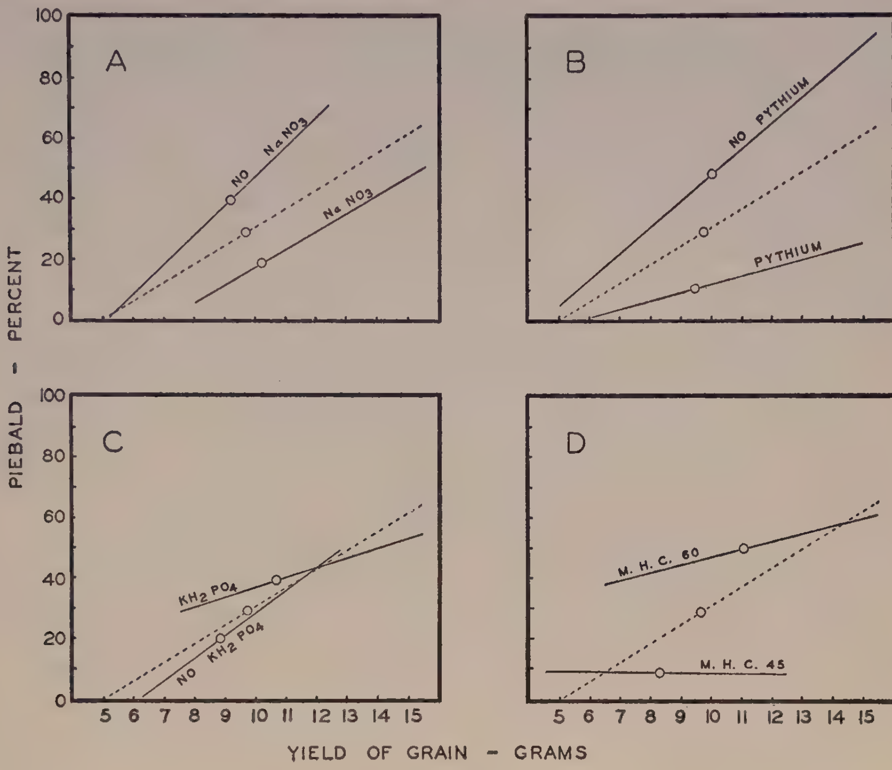

FIGURE 1. Regressions of percentage of piebald kernels on yield of grain as influenced by the following treatments: A, in the presence and absence of added $NaNO_3$; B, in the presence and absence of *Pythium arrhenomanes*; C, in the presence and absence of added KH_2PO_4; and D, at 60 per cent and 45 per cent of the moisture holding capacity (MHC) of the soil. The regression over all treatments is shown as a broken line in each part of the figure. The circles indicate the mean values for the various treatments.

The apparent dependence of percentage yellow berry on yield was investigated by means of regression lines. In Figure 1 the dotted lines represent the average regression of starchy kernels on yield for the experiment. It is evident that few or no starchy kernels occurred when yields of grain were 5 or 6 grams per crock. Above this level of yield, however, the percentages of yellow berry kernels increased with increases in yield. Essentially the same relationship existed whether the various treatments were present or absent. An exception to this statement occurs in Figure 1D where it appears that at a low moisture level there is no tendency for the percentage of starchy kernels to be related to yields. In fact at the moisture level of 45 per cent of the moisture holding capacity of the soil the kernels were almost 100 per cent vitreous except in the four units treated with KH_2PO_4, when 60 per cent of the kernels were starchy.

The relative positions of the regression lines of Figure 1, especially the means of the various treatments represented by open circles, illustrate the effects of the main treatments. In Figure 1C the addition of KH_2PO_4 increased yields of grain and also increased the percentages of yellow berry.

TABLE 7.—COEFFICIENTS OF CORRELATION BETWEEN PERCENTAGE OF STARCH KERNELS AND YIELD OF GRAIN IN THE SIXTH, EIGHTH AND TENTH CROPS IN A SERIES OF ROTATIONS CARRIED ON IN CROCKS IN THE GREENHOUSE

Crop	Degrees of freedom	Coefficient of correlation
Sixth	6	− 0.895**
Eighth	6	− 0.831**
Tenth	6	− 0.827*
All 3 crops	22	− 0.676**

N.B. One and two asterisks indicate significance attained at the 5 and 1 per cent levels, respectively.

Similarly the introduction of *P. arrhenomanes* reduced both the yield and the occurrence of starchy kernels, as did also the low level of soil moisture as compared to the optimum. On the other hand, the addition of nitrate caused an increase in yield and a decrease in yellow berry.

That the influence of nitrate content of the soil may overshadow the tendency for percentages of yellow berry to vary with yield is indicated in a series of rotation treatments which were carried on in four replications in crocks in the greenhouse, primarily for root disease studies. Two crops were grown each year and yellow berry appeared in the crops harvested in the spring. These were heavier crops than those harvested in the late fall, which did not show the yellow berry condition. Some of the rotations favoured the accumulation of nitrates as a result of nitrification during a summerfallow period, others as a result of the inclusion of sweet clover. Crops favoured by these conditions had few starchy kernels and yielded well. Those grown in soil after continuous cropping to wheat for six to ten crops showed the effects of nitrogen starvation as indicated in low yields of grain and high percentages of starchy kernels. Table 7 gives the coefficients of correlations between yellow berry and yield obtained under these conditions.

The correlation coefficients, Table 7, closely approximate or exceed the 1 per cent level of significance. Hence it may be concluded with considerable confidence that high levels of fertility (especially nitrates) as indicated by good yields also resulted in few or no starchy kernels. On the other hand, treatments designed to reduce fertility, particularly by draining out nitrates from the soil by frequent successive croppings to wheat, result in low yields of grain and high (60 to 90) percentages of yellow berry. While this evidence points to a deficiency of available nitrates as the primary cause of the starchy condition, much evidence exists that there are varietal differences in susceptibility to yellow berry.

TESTING VARIETIES FOR REACTION TO CONDITIONS FAVOURING DEVELOPMENT OF YELLOW BERRY

Information regarding nutritional or other factors which favour the formation of yellow berry may be of some value in testing varieties for susceptibility to this condition. Some of these factors are easily controlled

in greenhouse tests, such as moisture levels, use of phosphatic or potassic fertilizers and artificially inducing a deficiency of nitrates in the soil. This latter effect has been brought about by the junior author, in unpublished work, by means of leaching the soil with water to remove a considerable proportion of nitrogen from the soil.

A greenhouse experiment was designed to compare six varieties of wheat under conditions favourable to yellow berry. The varieties (Table 8) were selected on the basis of previous information to represent a wide variation of reaction to yellow berry. On February 2, 1951, each variety was planted in eight one-gallon crocks, each containing 4,400 grams (oven dry basis) of soil. The soil was a fairly fertile clay loam mixed at the rate of two parts to one part of sand by volume. The soil was fertilized with KH_2PO_4 at a rate equivalent to 200 pounds per acre. The moisture level was raised frequently to 65 per cent of the moisture holding capacity of the soil during the period of the experiment. Stands of plants were thinned at random to fourteen per crock, after removal of abnormal and weak seedlings. When the plants were in the sixth-leaf stage and again when in the shot-blade to early-flowering stage, four crocks of each variety were leached with five litres of water per crock to remove much or all available nitrates and possibly other soil solutes. Since about 700 ml. of the water was retained in the soil of each crock, similar amounts were added to the unleached crocks to bring them to approximately the same degree of saturation.

At maturity, data were obtained on yellow berry and yields of grain. The yellow berry data were calculated on the basis of three classes: (1) free from starchiness, (2) partially starchy or piebald, and (3) completely starchy or yellow berry. Giving these classes values of 0, 0.5 and 1, respectively, an index value in the scale 0 to 100 was assigned to each unit of the experiment. Since some variation was present between blocks and between varieties in time of ripening, data on relative maturity were obtained when

TABLE 8.—RELATIVE MATURITY, YIELDS OF GRAIN IN GRAMS PER CROCK, AND YELLOW BERRY INDICES (PERCENTAGES) IN WHEAT GROWN IN LEACHED AND UNLEACHED SOIL. VALUES ARE MEANS OF FOUR REPLICATES

Variety	Relative maturity		Yield		Yellow berry indices	
	Unleached	Leached	Unleached	Leached	Unleached	Leached
Garnet	10	5	9.2	7.1	3	11
Regent	16	15	9.6	7.9	4	30
Thatcher	17	16	10.8	8.8	24	61
Red Bobs	16	14	11.8	9.6	43	89
Marquis	18	20	10.7	9.5	42	92
Mindum	23	22	11.3	9.7	59	92
L.S.D. at 5% pt.	1.5		1.5		16	
L.S.D. at 1% pt.	2.0		2.2		22	

the first units of the experiment matured. The units were placed into six classes based on their relative stages of ripeness. These classes were given values of 1 for mature plants and 2, 3, 4, 5 and 6 for increasing degrees of immaturity. The data on maturity in Table 8 represent totals of the values for the four units of each variety in the leached or unleached series. Table 8 also gives the data on yields of grain and yellow berry, together with values of the least significant differences (L.S.D.) at the five and one per cent levels.

Leaching the soil to remove a large proportion of the soluble nutrients resulted in a substantial decrease in yield and an increase in the yellow berry indices (Table 8). This fact supports the suggestion that yellow berry results from a deficiency of nitrates, which are easily removed from the soil by leaching. In leached and unleached series alike the varietal differences in the yellow berry indices were quite large. There are evidently strong correlations between yield and yellow berry in data of both the leached and unleached series, as also between yield and maturity, and yellow berry and maturity. In view of the positive correlations found between yield and yellow berry as reported earlier in this paper, an analysis of covariance of the data was made holding both yield and stage of maturity constant. Table 9 shows tests of significance of the adjusted variety means, after removal of variances due to blocks and leaching of the soil.

The adjusted sum of squares for percentage of yellow berry was 4514, Table 9, indicating that a substantial portion of the unadjusted sum of squares, 16,238, is ascribable to simple correlation coefficients between yellow berry and yield (0.974) and between yellow berry and stage of maturity (0.824). Nevertheless the adjusted variety mean square, 903, is highly significant by the F test, indicating that the varieties of wheat in this experiment differ in their reactions to environmental factors favouring development of yellow berry. Further analysis indicates that the sum of

TABLE 9.—ANALYSIS OF COVARIANCE OF THE EFFECT OF YIELD AND STAGE OF MATURITY ON PERCENTAGE OF YELLOW BERRY KERNELS, TOGETHER WITH TESTS OF SIGNIFICANCE

Source of variance	Degrees of freedom	Yellow berry sums of squares	Errors of estimate			
			Sums of squares	Degrees of freedom	Mean square	F
Total	47	29,470	—	—	—	—
Blocks	3	1,307	—	—	—	—
Leaching	1	6,809	—	—	—	—
Variety × leaching	5	857	—	—	—	—
Variety	5	16,238	570	3	—	—
Error	33	4,259	3,317	31	107	—
Variety + Error	38	20,497	7,831	36	—	—
Difference for testing adjusted variety means		—	4,514	5	903	8.44*
Variety			570	3	190	1.78
Difference = error regression − variety regression			3,944	2	1,972	18.43*

* Asterisk indicates values of F exceed the 1 per cent level of significance.

TABLE 10.—PERCENTAGES OF YELLOW BERRY, MEANS OF UNLEACHED AND LEACHED SERIES, TABLE 8, COMPARED WITH ADJUSTED VARIETAL MEANS

Variety	Percentage of yellow berry	
	Uncorrected	Adjusted
Garnet	7	17
Regent	17	15
Thatcher	42	39
Red Bobs	66	70
Marquis	67	64
Mindum	75	65

squares for the difference between the error regression and the variety regression, 3944, is highly significant.

Table 10 shows that wide differences between varieties remain when percentages of yellow berry are adjusted for covariance with yield and stage of maturity. Garnet and Regent appear to have substantial resistance, Thatcher is intermediate, while Red Bobs, Marquis and Mindum apparently become starchy quite readily when environmental conditions are favourable.

DISCUSSION AND CONCLUSIONS

Most of the factors that have been reported as causing or influencing the appearance of yellow berry in wheat can be explained on the basis of their relation to nitrogen nutrition. Increases in starchiness resulting from applications of potassium or of phosphorus, a long post-floral period, and late maturity may all be the result of increasing the yields of grain without at the same time supplying adequate nitrogen to maintain the level of protein in the kernels. Similarly, reduction in available nitrates by leaching the soil, by late ploughing of summerfallow and by growing on podsolized soil (2) deprive the plants of adequate nitrates in relation to other factors. The decrease in starchiness reported as being associated with low soil moistures and root infections by *Pythium arrhenomanes*, a short post-floral period, and early maturity appear to be explainable on the basis of reductions in yield of grain to the point where available nitrates are ample to raise the protein contents of the kernels beyond the point where starchiness occurs.

The relation between yields and yellow berry has been pointed out by Lyon and Keyser (9) and Swanson (15). In the reported instances where stem rust and leaf rust infections of wheat plants increased yellow berry in the kernels possibly the rust fungi interfered with normal transport of proteins from leaves and stems to the kernels.

Partial or complete control of yellow berry in wheat with nitrate fertilizers has been reported by Jones and Mitchell (8) and Headden (6). Other authors found that starchy or piebald kernels generally have lower percentages of protein than unaffected kernels of the same sample (Table 1).

Anderson and Aitken (4) report a rather low correlation coefficient of -0.61 between protein content and percentage of starchy kernels in 33 samples of Thatcher wheat, each showing some starchy kernels. They found that the protein contents of starchy, piebald, and vitreous kernels have overlapping protein ranges; the mean protein levels were: starchy 9.6 per cent, piebald 10.7 per cent, and vitreous 13.0 per cent. It appears from their results that starchiness as shown in yellow berry is partially but not closely related to protein content. In this connection it may be stated that the junior author, in unpublished work, has demonstrated that an opaque, starchy condition may be induced in vitreous samples of wheat, simply by soaking in water, followed by drying. Roberts and Freeman (12) distinguish between a similar condition as a result of weathering in the field and yellow berry. Unless weathered seed is clearly distinguished from yellow berry a low degree of correlation between protein content and percentage of vitreous kernels might be obtained by inclusion of a number of samples of high protein content with starchiness induced in the fields after maturity by periods of wet weather.

Unlike Anderson and Aitken, Aamodt and Torrie (1, 2) found in their crosses that correlation coefficients between kernel texture and protein content were very strong and positive, when the lines were grown on gray podsol soils. Thus, they found that kernel texture is of considerable value in discarding lines of low quality. To differentiate between lines for kernel texture, they suggested growing the material on gray podsolized soil under an environment such as is found at Fallis, Alberta.

The present work demonstrates the possibility of securing a differentiation between varieties for kernel texture under controlled conditions in the greenhouse, by making use of some of the conditions which are known to favour development of yellow berry. Length of day may influence differentially the time of flowering of certain varieties and lines. Hence it may be advisable to carry on such a test at a time when flowering in any of the varieties is not influenced by short days, or to use artificial lighting to overcome this possibility.

Deficient nitrogen nutrition during the post-floral period in relation to the general level of photosynthetic activity appears to be the primary factor favouring the production of starchy kernels. A secondary and contributing factor is the varietal tendency for the development of the condition.

Control of yellow berry appears to depend partly on the use of those varieties which are least subject to starchiness, the use of nitrogenous fertilizers, and other means of maintaining the fertility of the soil with respect to nitrates, such as the growing of legumes.

ACKNOWLEDGMENT

The authors are indebted to T. C. Vanterpool, University of Saskatchewan, for the culture of *Pythium arrhenomanes* used in their studies.

REFERENCES

1. Aamodt, O. S., and J. H. Torrie. Kernel texture as an indicator of quality in hard red spring wheats. Can. J. Res., *C*, 13 : 79-88. 1935.
2. Aamodt, O. S., and J. H. Torrie. Studies on the inheritance of and the relation between kernel texture and protein content in several spring wheat crosses. Can. J. Res., *C*, 13 : 202-219. 1935.
3. Alsberg, C. L., and E. P. Griffing. Environment, heredity and wheat quality. Wheat studies of the Food Research Inst., Stanford University 10 : 229-249. 1934.
4. Anderson, J. A., and T. R. Aitken. Incidence and protein contents of starchy and piebald kernels in Canadian wheat. Board of Grain Commissioners, Grain Research Laboratory, 20th Ann. Rept. 1946 : 10-11. 1947.
5. Caldwell, R. M., H. R. Kraybill, J. T. Sullivan, and L. E. Compton. Effect of leaf rust (*Puccinia triticina*) on yield, physical characters, and composition of winter wheats. J. Agr. Res. 48 : 1049-1071. 1934.
6. Headden, W. P. Yellow berry in wheat. Colo. Agr. Expt. Sta. Bull 205. 1915.
7. Heald, F. D. Manual of plant diseases. McGraw-Hill, New York. 1926.
8. Jones, J. S., and G. A. Mitchell. The cause and control of yellow berry in Turkey wheat grown under dry-farming conditions. J. Agr. Res. 33 : 281-292. 1926.
9. Lyon, T. L., and A. Keyser. Nature and cause of "yellow berry" in winter wheat. Nebr. Agr. Expt. Sta. Bull. 89 : 23-36. 1905.
10. Minz, Gershon. Yellowberry and stem rust in wheat. Phytopath. 36 : 381-383. 1946.
11. Mitchell, J., H. C. Moss, and J. S. Clayton. Soil survey of Southern Saskatchewan. Report No. 12. Univ. of Sask., Saskatoon. 1944.
12. Roberts, H. F., and G. F. Freeman. The yellow berry problem in Kansas hard winter wheats. Kansas Agr. Exp. Sta. Bull. 156. 1908.
13. Shollenberger, J. H., and D. A. Coleman. Relation of kernel texture to the physical characteristics, milling and baking qualities and chemical composition of wheat. U.S.D.A. Dept. Bull. 1420. 1926.
14. Shutt, F. T. Report of the chemist. *In* Dominion Dept. of Agr. Experimental Farms Reports for the year ending March 31, 1908, pp. 135-143. 1908.
15. Swanson, C. O. Wheat and flour quality. Burgess Pub. Co., Minneapolis, Minn. 1938.

EFFECT OF CULTIVATION ON THE ORGANIC MATTER AND NITROGEN OF BROWN SOILS[1]

J. L. Doughty[2], F. D. Cook[3] and F. G. Warder[4]

Soil Research Laboratory, Swift Current, Sask.

[Received for publication January 24, 1954]

ABSTRACT

The brown soils of the prairie area of western Canada lose organic matter and nitrogen very rapidly when put under cultivation. The loss of organic matter is directly related to bacterial activity and the evolution of carbon dioxide. Experimental results are presented showing losses up to 26 per cent of the organic matter and 33 per cent of the nitrogen from soils that have been under cultivation for 14 years. Only part of the loss of nitrogen can be accounted for by crop removal. Experimental evidence is presented to show that some nitrogen is lost by leaching of nitrates beyond the depth of root penetration. Nitrogen was also lost in some gaseous form, other than as ammonia.

INTRODUCTION

The rapid loss of organic matter and nitrogen from the prairie soils of western Canada was first shown by Shutt in 1905. Further data (6) were presented by him in 1925 for soil samples from the same and other locations. Comparisons were made, where possible, of the loss during the first 25 years under cultivation and the following 20 years. The annual loss during the latter period was not as great as during the early years of cultivation.

A second survey of this nature was conducted by Caldwell, Wyatt, and Newton (2), starting in 1937 and covering the 5 soil zones of the three prairie provinces. The results showed an average loss of 24 per cent of the organic matter and 17 per cent of the nitrogen from the 0-6 inch layer of the brown soils. Losses from the lower depths were not as great. The data also indicated that the average annual loss from soils cultivated for only 9 years was greater than the annual loss from soils cultivated for 28 years. Somewhat similar results were found for the dark brown and black soils.

In both of these surveys, losses were computed from the differences found between virgin sod and adjacent cultivated fields, the assumption being that the virgin sod represented the chemical composition of the cultivated field at the time it was broken.

Laboratory experiments by Lehane and Staple (5) showed a loss of 15 per cent of the organic matter from samples of crested wheatgrass sod in a period of 10 months. In other experiments at this Laboratory by Doughty (3) it was found that virgin sod lost organic matter at a rate equal to 2500 pounds per acre per month, while soil from cultivated fields lost 1000 pounds per acre per month. These losses were calculated from the carbon evolved as carbon dioxide under favourable conditions of temperature and moisture. The loss of organic matter is definitely related to bacterial activity with the evolution of carbon as carbon dioxide.

---

[1] Contribution from Division of Field Husbandry, Soils and Agricultural Engineering, Experimental Farms Service, Canada Department of Agriculture.
[2] Officer-in-Charge.
[3] Soil Bacteriologist.
[4] Soil Chemist.

Nitrogen may be lost from the soil by crop use, leaching or in a gaseous form. Calculations by Shutt (6) showed that less than half the loss could be attributed to crop removal. Caldwell *et al.* (2) stated that less than half the loss from the surface 6 inches of cultivated soil could be accounted for by crop use, and assumed that little if any loss was due to leaching in the brown soil zone. Numerous tests at this Laboratory, of the gases evolved by incubating soils under favourable moisture conditions, have failed to show the presence of ammonia.

Jones (4), using tagged nitrate nitrogen, found that nitrogen was lost in some gaseous form other than ammonia from soils kept under partial oxygen pressure. While the denitrification and loss were greater at the lower oxygen pressures, there was measurable loss of nitrogen under conditions that could be considered aerobic. Broadbent and Stojanovic (1) found that denitrification occurred at all oxygen levels but that the reduction to ammonia was negligible. The maximum recovery of added nitrate was 75 per cent under fully aerobic conditions. It would seem logical to assume that where nitrates tend to accumulate as in a fallowed brown soil, conditions favourable for denitrification and subsequent loss of gaseous nitrogen may exist at certain times.

FIELD EXPERIMENTS

Soil samples were collected from two fields of new breaking in 1939 and from a third field in 1941. These fields were sampled at the same locations in subsequent years and the organic matter and nitrogen determined. Total carbon was determined by dry combustion at 900° C. and absorption of the CO_2 in NaOH. Organic carbon was taken as the difference between total carbon and inorganic carbon, as determined by digestion in dilute HCl and absorption of the CO_2 in NaOH. Organic matter was computed by multiplying organic carbon by the factor 1.724. Nitrogen was determined by the Gunning-Hibbard method using selenium as an additional catalyst.

The organic matter and nitrogen content of the soils at the time of breaking and at present are recorded in Table 1. The losses were relatively high in all cases considering the comparatively short period of cultivation. The relatively slower rate of loss shown by the clay loam soil is not considered to be a definite function of soil texture. Even at the slower rate,

TABLE 1.—EFFECT OF CULTIVATION ON ORGANIC MATTER AND NITROGEN

Soil	Depth	Years cult.	Organic matter			Nitrogen		
			Initial	Present	Loss	Initial	Present	Loss
	%	%	%	%	%	%	%	%
Haverhill loam	0–12	14	3.43	2.51	26.8	0.224	0.154	31.3
Wood Mountain loam	0–12	14	3.71	2.83	23.7	0.248	0.164	33.8
Wood Mountain clay loam	0–12	12	5.01	4.15	17.2	0.288	0.232	19.4

there has been a very definite loss. Analyses of samples collected during the intervening years showed that the annual rate of loss was greater during the first 5 or 6 years than during the latter half of the period. Soil samples from adjacent fields that had been cultivated for 30 to 40 years contained lower amounts of organic matter and nitrogen than shown in Table 1, indicating that further reductions can be expected.

NITROGEN LOSS BY LEACHING

Deep sampling of a fallowed field following early fall rains showed high concentrations of nitrate at a depth of 7 feet. This was some 3 feet beyond the normal depth of root penetration of cereals. As there would be no upward movement of the nitrate, this represented a loss of nitrogen for plant growth.

Additional soil samples were collected the following spring from virgin sod and adjacent cultivated fields to depths of 8 to 10 feet. The organic matter, nitrogen and nitrate nitrogen were determined. The results are reported in Table 2. A comparison of the virgin and cultivated soils shows an appreciable reduction in the organic matter and nitrogen content of the cultivated soils. Erosion may have accounted for some of the loss but visual evidence of serious erosion was not apparent.

TABLE 2.—CHEMICAL COMPOSITION OF VIRGIN AND CULTIVATED SOILS

Soil	Depth	Virgin			Cultivated		
		O.M.	N	N as NO_3	O.M.	N	N as NO_3
	ft.	%	%	p.p.m.	%	%	p.p.m.
Wood Mountain clay loam	0 – 1	4.12	0.204	1	2.41	0.141	6
	1 – 2	1.58	0.097	1	1.24	0.080	5
	2 – 3	2.13	0.055	1	1.51	0.034	5
	3 – 4	1.19	0.027	2	1.24	0.099	5
	4 – 5	1.02	0.015	1	0.79	0.014	10
	5 – 6	0.67	0.017	<1	0.77	0.026	61
	6 – 7	0.67	0.024	<1	0.77	0.016	15
	7 – 8	0.53	0.016	1	0.71	0.017	12
Cypress clay loam	0 – 1	3.15	0.174	<1	2.31	0.149	8
	1 – 2	1.81	0.096	1	1.51	0.065	4
	2 – 3	1.55	0.058	1	1.46	0.034	5
	3 – 4	1.45	0.029	1	1.17	0.025	3
	4 – 5	0.93	0.020	<1	0.81	0.027	7
	5 – 6	0.81	0.019	1	0.15	0.006	11
	6 – 7	0.07	0.006	1	0.10	0.004	8
	7 – 8	0.08	—	3	0.15	0.004	< 1
Sceptre clay	0 – 1	3.24	0.192	<1	2.10	0.116	<1
	1 – 2	2.22	0.125	<1	1.45	0.073	<1
	2 – 3	2.03	0.095	13	1.57	0.063	<1
	3 – 4	1.37	0.052	11	1.47	0.060	<1
	4 – 5	1.48	0.052	3	1.19	0.047	6
	5 – 6	1.53	0.075	<1	1.21	0.045	8
	6 – 7	1.43	0.075	<1	1.17	0.050	5
	7 – 8	1.37	0.058	<1	1.21	0.046	8
	8 – 9	1.10	0.048	<1	1.21	0.050	8
	9 – 10	1.08	0.038	<1	1.21	0.042	11

The lack of nitrate nitrogen in the lower depths of the virgin soil and the presence of nitrates at the same depths of cultivated soil as shown in Table 2 are of particular interest.

The moisture content of the virgin soils was close to the wilting percentage at a depth of 3 feet. Below this depth the moisture content was slightly higher but still much below field capacity. Extensive sampling has shown that grass crops, either native or cultivated, generally use all the available moisture and very little ever penetrates beyond the depth of root growth. Fall samplings of sod after summers with high precipitation have shown dry soil at a depth of 3 feet. This rapid use of moisture and nitrate by grass crops would tend to prevent any loss of nitrate by leaching.

The cultivated soils were wet to field capacity to the depth of sampling. Under fallow conditions the accumulation of nitrates in the surface soils is quite rapid. Nitrates, being readily soluble and not adsorbed by the colloidal complex, are free to move downward whenever the precipitation is sufficient to wet the soil above field capacity. Systematic sampling of fallow fields over the past 15 years has shown that moisture does not penetrate below the depth of the root zone except in years of high precipitation. Nitrates, if present in the surface layers, would be carried downward by the percolating moisture.

The nitrate nitrogen found in the cultivated soils at depths below 4 feet may represent several seasons' accumulation or only part of one season's leaching. In either case, this nitrate is a definite loss in so far as the sampled area is concerned. Incubation tests of the soil samples from the lower depths showed that nitrifying bacteria were not present. Any nitrate present must have been carried down by the percolating water.

The total amounts of nitrogen as nitrate found below a depth of 4 feet are shown in Table 3. While these amounts are not large in comparison with the total loss of nitrogen, as shown in Table 2, they constitute evidence that loss of nitrogen by leaching does occur in the brown soils. It would seem logical to expect greater loss by leaching in areas of higher precipitation. Insufficient data are available to permit a calculation of the total loss of nitrogen by leaching.

TABLE 3.—NITROGEN AS NITRATE BELOW ROOT ZONE

Depth	Wood Mountain clay loam	Cypress clay loam	Sceptre clay
ft.	lb./acre	lb./acre	lb./acre
4 – 5	40	28	24
5 – 6	244	44	32
6 – 7	60	32	20
7 – 6	48	—	32
8 – 9	—	—	32
9 – 10	—	—	44
Total	392	104	184

LOSS OF GASEOUS NITROGEN FROM FALLOWED SOIL

Soil was collected from the surface 6 inches of virgin sod and of adjacent cultivated fields. The soils were air-dried, coarsely ground and placed in glazed gallon crocks in triplicate. Water was added to bring the moisture up to field capacity and the crocks were placed in the greenhouse. No crops were grown and nothing was added except rain water, the moisture content being brought up to field capacity at intervals.

After 5 years of this fallow treatment, the crocks were emptied, the soil air-dried, thoroughly mixed and a sample taken from each crock for analysis. The salicylic acid method to include nitrate was used in determining nitrogen.

The data in Table 4 show the organic carbon and total nitrogen, in the soils before and after the 5-year fallow period. All of the soils lost a large amount of carbon, the loss varying from 18.6 to 24.3 per cent. The virgin soils lost more carbon than the corresponding cultivated soils, a fact which is attributed to a higher content of easily decomposable organic matter. These losses were of the same general order as found under field conditions for an equivalent period.

The loss of nitrogen varied from 5.0 to 9.1 per cent, with the loss being higher in the virgin soils. These losses were much lower than found under field conditions for an equivalent time period. The loss of nitrogen under field conditions was of the same general magnitude on a percentage basis as the loss of organic matter. This loss of nitrogen must be attributed to the evolution of nitrogen in some gaseous form, for under the conditions of this experiment there was no loss by crop removal or leaching. It is suggested that denitrification may have taken place with the evolution of elemental nitrogen or an oxide, for repeated tests have failed to show the evolution of ammonia by incubating soils under similar conditions of temperature and moisture.

TABLE 4.—EFFECT OF CONTINUOUS FALLOW ON ORGANIC MATTER AND NITROGEN OF SOIL IN GLAZED CROCKS

	Original		After 5 years		Loss	
	O.M.	N	O.M.	N	O.M.	N
	%	%	%	%	%	%
Wood Mountain clay loam—						
Virgin	6.55	0.340	4.96	0.309	24.3	9.1
Cultivated	4.86	0.264	3.89	0.245	19.9	7.2
Sceptre clay—						
Virgin	4.71	0.294	3.71	0.270	21.2	8.2
Cultivated	3.34	0.221	2.72	0.210	18.6	5.0

REFERENCES

1. Broadbent, F. E., and B. F. Stojanovic. Effect of partial pressure of oxygen on some soil nitrogen transformations. Proc. Soil Sci. Soc. 16 : 359-363. 1952.
2. Caldwell, A. C., F. A. Wyatt, and J. D. Newton. Effect of cultivation and cropping on the chemical composition of some western Canada prairie soils. Sci. Agr. 19 : 258-270. 1939.
3. Doughty, J. L. The maintenance of organic matter in the brown soils. Sci. Agr. 28: 88-95. 1948.
4. Jones, E. J. Loss of nitrogen from soils under an aerobic condition. Soil Sci. 71 : 193-196. 1951.
5. Lehane, J. J., and W. J. Staple. The effect of crested wheatgrass on some physical and chemical characteristics of the soil. Sci. Agr. 23 : 509-517. 1943.
6. Shutt, F. T. Influence of grain growing on the nitrogen and organic matter content of the western prairie soils of Canada. Dom. of Canada, Dept. of Agr. Bull. 44., n.s. 1925.

POTATO DIGGER OPERATION AND ITS EFFECT ON TUBER BRUISING

A. I. MAGEE

Division of Field Husbandry, Soils and Agricultural Engineering, Department of Agriculture, Ottawa, Canada

[Received for publication August 13, 1953]

ABSTRACT

A field test was conducted by the Central Experimental Farm, Ottawa, to investigate the influence of three adjustments of a power-take-off elevator digger on its operation, namely, agitation of chain vs. no agitation, speed of elevator operation, and low gear vs. second gear tractor operation.

The data showed that agitation had a marked effect on injury increasing it by seven times. Various speeds of elevator operation did not produce significant trends. Second gear tractor operation significantly reduced the amount of injury compared to low gear operation.

Soil conditions were moist on half of the test and rather wet for the remainder of the test. The wet soil conditions obliterated all differences between various adjustments and injury was at a low level.

Mechanical injury or tuber bruising is one of the most important factors affecting the quality of potatoes reaching the market.

Hastings (1) of North Dakota in 1931 reported that 70 per cent of defects found on inspection of 1,050 cars of potatoes were attributed to mechanical injury. A later survey indicated that about 40 per cent of the injury was caused by the digger. Werner (2) in Nebraska found that 16 to 31 per cent of the crop produced in 1928 to 1931 was mechanically injured. Hardenburg (3) of Cornell University reported 10 per cent of the tubers dug in 1931 were bruised or cut by the digger.

Several factors affect the amount of injury caused by the digging operation. Hardenburg (3) reported that injury decreased as the depth of the digger point was increased, from 10.8 per cent with a shallow setting to 4.2 per cent with a relatively deep setting. He also found that agitation of the elevator chain increased injury from 0.75 per cent with no agitation to 4.5 per cent with agitation. The speed of the elevator chain may be controlled by a transmission on some diggers, and Hardenburg (3) reported the injury to be 2.3 per cent in low gear, 7.6 per cent in intermediate gear and 15.0 per cent in high gear. Long (5) of North Dakota in 1944 found that a minimum injury occurred at an elevator speed of 220-240 feet per minute while a lower or higher speed increased injury. Humphrey (6) of Idaho in 1950 recommended an elevator speed of 150 feet per minute or less, and minimum use of the kickers or agitators.

Since the results of the tests on digger operation are quite variable, an experiment was conducted in 1952 by the Field Husbandry Division to determine the best method of operating a potato digger. Three factors of digger operation were investigated, namely: (1) with and without kickers or agitators; (2) at six different operating speeds; (3) with the tractor in first and in second gear. These tests were conducted on four replicated plots on Manotick sandy loam. Each plot consisted of 12 rows. One-half the plot was dug with agitators or kickers on the digger while the other half was dug with plain rollers under the elevator chain. On each half the digger was operated at six different operating speeds and with each operating speed the tractor was driven in low gear and in second gear.

An International one-row power-take-off elevator digger, with a 24 in. by 9 ft. elevator chain, was used for the test and was drawn by a 2-3-plough tractor. Belting was installed on the digger to prevent the tubers from striking the ends of the elevator chain.

Twenty-four samples of approximately 50 pounds each were taken from each plot, one representing each treatment, and examined for injury. The extent of the injury was recorded as the per cent of the tuber cut off to remove the damaged section of the potato (7). Each injury was placed into one of three groups: (*a*) 2 to 5 per cent injury; (*b*) 5 to 10 per cent injury; (*c*) 10 per cent or more. An injury index was calculated by multiplying the 2 to 5 per cent group by 0.1, the 5 to 10 per cent group by 0.5 and the over 10 per cent group by 1.0. Thus, the injury index was a measure of the actual extent of the tuber damage.

The four plots were harvested on two separate days, two plots were dug the first day when soil conditions were moist, but the other two plots were dug two days later after a rain and the soil was rather wet but not sticky. Data were statistically analysed and Table 1 shows that the results differ significantly on the separate days.

TABLE 1.—ANALYSIS OF VARIANCE OF THE EFFECT OF SOIL CONDITIONS ON SEPARATE DAYS ON THE TUBER INJURY INDEX

Source	D.F.	M.S.	F
Days	1	30.7587	8664.4**
Error	2	0.0035	—

** Significant at P = 0.01.

Because there was considerable difference between days of operation, the data for each day were examined separately as shown in Table 2.

TABLE 2.—ANALYSIS OF VARIANCE OF THE INJURY INDEX FOR EACH DAY

Source	D.F.	Day 1		Day 2	
		M.S.	F	M.S.	F
Agitation	1	77.8516	133.54**	0.6792	4.83
Error	2	0.5829	—	0.1407	—
Operating Speeds	5	2.5238	1.41	0.3887	1.87
Operating Speeds × Agitation	5	2.1608	1.21	0.3821	1.84
Error	10	1.7912	—	0.2076	—
Traction Speed	1	28.9076	17.21**	0.0841	1.25
Traction Speed × Agitation	1	26.0043	15.51**	0.1464	2.17
Traction Speed × Operating Speed	5	2.6542	1.58	0.2729	4.05*
Error	17	1.6771	—	0.0673	—

* Significant at P = 0.05.
** Significant at P = 0.01.

Agitation caused significant differences in Day 1. The traction speed of the digging operation was also significant as well as the interaction of traction speed on agitation.

Discussion of Data

The potatoes from the two plots harvested on the first day had a higher amount of tuber damage than the samples from the plots harvested on the second day.

On Day 1 soil conditions permitted moderate movement of the soil through the digger chain and the tubers were not protected by a cushion of soil on the chain. However, on Day 2 the damp soil resulting from the heavy rain was carried on the chain and provided a thick soil cushion that reduced the tuber injury.

The reduction in injury index was accompanied by a reduction in major injury from 8.3 to 4.0 per cent and minor injury from 34.7 to 18.3 per cent.

The agitation of the elevator chain using kickers or agitators caused a significant increase in the amount of tuber injury on Day 1. There was no significant difference on Day 2.

The increase in injury index on Day 1 was accompanied by an increase in major injury from 3.1 to 13.5 per cent and minor injury from 23.5 to 45.9 per cent.

On Day 1 soil conditions permitted efficient operation without the use of agitation, but on Day 2 the soil did not move readily through the chain and agitation was necessary for efficient separation of the tubers from the soil.

Tuber injury was decreased by an increase in the forward speed of travel of the digging equipment with damp soil conditions.

Table 3.—Effect of soil conditions on separate days on tuber injury

	Day 1	Day 2	L.S.D.	
			P. 0.05	P. 0.01
Injury index	1.69	0.56	0.05	0.12

Table 4.—Effect of agitation on tuber injury

Adjustment	Day 1		L.S.D.		Day 2		L.S.D.
	No agita'n	With agita'n	P = 0.05	P = 0.01	No agita'n	With agita'n	
Injury index	0.41	2.96	0.95	2.18	0.44	0.68	No dif.

FIGURE 1. The adjustment and operation of an elevator potato digger govern the number of potatoes damaged during the digging operation.

TABLE 5.—EFFECT OF TRACTION SPEED ON TUBER INJURY

Traction speed	Day 1		L.S.D.		Day 2		L.S.D.
	Low gear	2nd gear	P= 0.05	P= 0.01	Low gear	2nd gear	
Injury index	2.46	0.91	0.79	1.08	0.60	0.50	No dif.

TABLE 6.—EFFECT OF OPERATING SPEED ON TUBER INJURY

Operating speed (r.p.m. of P.T.O.)	Day 1			L.S.D. P=0.05	Day 2			L.S.D. P=0.05
	225	350	550		225	350	550	
Injury index	0.9	2.6	1.4	1.5	0.4	0.4	0.7	0.5

The reduction in injury index on Day 1 was accompanied by a reduction in major injury from 11.2 to 5.4 and minor injury from 39.0 to 30.4 per cent.

The reduction in injury on Day 1 at the higher traction speed was produced by the cushion of soil on the chain. The moist sandy loam soil did not fall through the chain as rapidly at the increased forward speeds and more soil was carried on the chain with the tubers.

On Day 2 with rather wet soil conditions both slow and fast forward speeds resulted in a thick soil cushion and no difference in injury was recorded.

The operating speed did not have a marked effect on the amount of tuber injury.

As with the previous comparisons the difference between the two days is very noticeable. The reduction in injury index was accompanied by an average reduction in major injury from 8.2 to 3.5 and in minor injury from 37.3 to 17.3 per cent.

Speed of operation is often blamed for tuber injury but in this test more of the moist soil was carried on the chain as the speed increased and this apparently offset the influence of increased chain speed and resulted in no definite trend in tuber damage.

The interaction of traction speed on agitation was significant and Table 7 shows the amount of the interaction.

TABLE 7.—INTERACTION OF AGITATION ON TRACTION SPEED IN DAY 1

Traction speed	Injury index		
	Low gear	Second gear	Decrease
With agitation	4.47	1.45	3.02
No agitation	0.45	0.37	0.08
Decrease	4.02	1.08	—

The interaction shows that it is more important to operate in second gear when kickers or agitators are used than when there is no agitation.

In conclusion, a summary of the results of this test provides the following recommendations for the proper operation of an elevator potato digger:

(1) Do not use kickers or agitators on the digger unless the potatoes are being buried in soil.

(2) Adjust elevator speed and traction speed to maintain a soil cushion on the elevator chain.

(3) Use particular caution under dry or sandy soil conditions and when a soil cushion is difficult to maintain.

REFERENCES

1. Hastings, R. C. Mechanical injury to potatoes and its eradication in North Dakota. Amer. Potato J., May 1931, p. 126.
2. Werner, H. O. The cause and prevention of mechanical injuries to potatoes. Nebraska Agr. Expt. Sta. Bull. 260. 1931.
3. Hardenburg, E. V. Causes and prevention of potato tuber defects at harvest time. Amer. Potato J., September 1933, pp. 173-176.
4. Hardenburg, E. V. Potato digger adjustment in relation to tuber bruising. Amer. Potato J., August 1940, pp. 191-197.
5. Long, E. L. What speed of operation for a potato digger causes the least amount of injury? Bi-monthly Bulletin Vol. 6, No. 6, p. 15. 1944.
6. Humphrey, Elmer. Steps that can be taken to reduce mechanical damage to potatoes at harvest time. Idaho Expt. Sta. Bull. 278. 1950.
7. Lutz, J. M., *et al.* Reducing injuries in grading stored potatoes. Amer. Potato J., October, 1952, p. 234.

ASCOCHYTA DISEASES OF PEAS IN CANADA—WITH SPECIAL REFERENCE TO SEED TRANSMISSION[1]

By A. J. Skolko, J. W. Groves and V. R. Wallen[2]

Botany and Plant Pathology Division, Ottawa, Canada

[Received for publication January 19, 1954]

ABSTRACT

Over 90 identified species of fungi have been isolated from surface sterilized pea seeds germinated on an agar medium. Of the known pathogenic fungi, species of *Ascochyta* were the most frequently isolated from seed. From the examination of almost 5000 Canadian pea seed samples over a 12-year period, it was found that 51 per cent of the samples were infected with *Ascochyta* spp.; 18 per cent were heavily infected. Of the Ascochyta-infected samples, 85 per cent were infected with *A. pisi*. Pea seed grown in Eastern Canada was more heavily infected than seed grown in the western provinces of Alberta and British Columbia. Varietal susceptibility of a number of commercial pea varieties was tested by plant inoculation in the field using a mixture of 10 isolates of *A. pisi*. Some varieties which showed abundant disease symptoms in the field produced relatively disease-free seed and, conversely, some varieties which appeared to be highly resistant sometimes produced heavily infected seed.

INTRODUCTION

As early as 1936, when work on seed-borne diseases was first undertaken at this laboratory under the direction of the late G. A. Scott, it was apparent that, of the numerous species of fungi associated with pea seed produced in Canada, the most important pathogens were those responsible for the so-called Ascochyta diseases. Field observations have corroborated this conclusion. In the absence of other control measures and of any practical source of resistance in commercial varieties, the use of disease-free seed has been advocated. In the report that follows the species of fungi which we have isolated from pea seed are listed without reference to their pathogenic potential. However, the distribution and severity of the Ascochyta diseases, as determined from field reports and from laboratory seed examinations made during the period from 1939 to 1950, are dealt with more fully. In the search for parental material possessing resistance to *Ascochyta pisi* Lib., many pea varieties have been tested by inoculation in the field and the results of these tests are also included.

The annual production of field peas in Canada, from estimates in the Quarterly Bulletin of Agricultural Statistics, published by the Canada Department of Agriculture and based on the average for the period 1944-48, amounted to over $1\frac{1}{2}$ million bushels while the annual production of garden peas, averaged for the period 1940-49, was almost 63 million pounds. The bulk of the pea production is in the eastern provinces of Ontario and Quebec, whereas seed production, especially of garden pea varieties, is to be found chiefly in western Canada in Alberta and British Columbia, although Ontario still produces an appreciable quantity. The concentration of pea seed production in western Canada can, in part, be attributed to the fact that the dry western climatic conditions are less favourable for disease development, a situation similar to that in the United States where semi-arid areas in the western states produce the bulk of disease-free pea seed.

[1] Contribution No. 1354 from the Botany and Plant Pathology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Senior Plant Pathologist, Principal Mycologist, and Associate Plant Pathologist, respectively.

SYMPTOMS

Jones (16) established that the disease formerly referred to as Ascochyta blight was actually a complex of three distinctly recognizable diseases caused by three species of *Ascochyta*. He proposed that the terms Ascochyta leaf and pod spot, Mycosphaerella blight, and Ascochyta footrot be applied to the diseases caused by *Ascochyta pisi* Lib., *Mycosphaerella pinodes* (Berk. & Blox.) Vestergr. (=*Ascochyta pinodes* (B. & Br.) Jones), and *Ascochyta pinodella* Jones, respectively. Ascochyta leaf and pod spot (*A. pisi*) takes the form of circular tan spots with dark brown margins on the leaves and pods, and somewhat elongated lesions on the stems. When infection is severe the pods and seeds may be heavily spotted and deformed or pod development may be arrested. With Mycosphaerella blight (*M. pinodes*), the spotting of the leaves is brown to purplish, irregular in outline, and without a definite margin. Brown to purplish irregular dots appear on the pods and these dots may become irregularly enlarged. On the stems, black to purple streaks appear, especially at the nodes and on the lower portion of the stem. Ascochyta footrot(*A. pinodella*) resembles Mycosphaerella blight except that symptoms on the leaves and pods are uncommon and infection is confined to the lower portion of the stem. Morphological and cultural characters of the three species are sufficiently distinctive to allow for their identification without difficulty (12).

DISTRIBUTION

The Ascochyta diseases of peas probably occur wherever peas are grown, but are limited in their severity by climatic conditions. In semi-arid regions where low precipitation is unfavourable for disease development generally, diseases caused by *Ascochyta* spp. present no serious problem. Prior to 1927 when Jones (16) and Linford and Sprague (17) established the identity of the three species of *Ascochyta*, the occurrence and relative importance of each species cannot be determined. Most reports of serious losses since 1927 in the field have been attributed to *Mycosphaerella pinodes*, yet the results of seed examination show that *Ascochyta pisi* is the predominant species infecting the seed. *Ascochyta pinodella* is least commonly encountered in seed but has been responsible for considerable losses in western Washington (11). *A. pinodella* has not been found in Russia but a closely related species, *Ascochyta pseudopinodella* Bond.-Mont. & Vass., has been reported (1). Because all three species, *A. pisi*, *M. pinodes*, and *A. pinodella*, can be transmitted by seed, their distribution to all major pea growing regions undoubtedly has been facilitated.

Reports of recent years from the United States indicate that the Ascochyta diseases were of much greater consequence before the disease-free western-grown pea seed came into use. Jones & Linford (15) state that *Ascochyta* (*pinodes* ?) was abundant and important in Wisconsin about 1911 but by 1924 it had almost disappeared. Linford and Sprague (17) found that although *A. pisi* was more commonly seed-borne, *Mycosphaerella pinodes* was probably the cause of severe outbreaks of Ascochyta disease. Walker and Hare in 1943 (29) showed that there had been an increase in damage in Wisconsin but rated Ascochyta blight fourth in importance of the major pea diseases. Hare and Walker (12) state that there was

moderate to severe damage in 25 and 30 per cent of the fields surveyed in 1943 and 1944, respectively. Jones (16) recorded extreme damage to the pea crop during 1925 in New York as having been caused by *M. pinodes*. Weaver (32) reported that Ascochyta blight was increasing in Pennsylvania and had become most destructive in 1945. In Minnesota, Starr (27) reported that leaf and pod spots caused by *A. pisi* and *M. pinodes* were very limited and of no great economic importance. Reinking (25) considered *A. pinodella* to be of secondary importance to other root-rot fungi in western New York state whereas Gould (11) found that footrot caused mainly by *A. pinodella* had become destructive in western Washington. Attempts to breed resistant varieties of winter peas by Weimer (35), Ogden (22), and Seal (26) attest to the importance of the disease in the southern states. Horn and Atkins (13) report the occurrence of all three diseases in Louisiana.

The work of Butler (2), Wark (30, 31), and Stubbs (28), concerned with the development of sources of disease-free seed and control by seed treatment, indicates that the Ascochyta diseases are of some importance in Australia. Jauch (14) has observed *M. pinodes* in epidemic form on peas in the Argentine throughout the humid districts. In Europe, Ogilvie and Mulligan (23) and Moore (19) report the diseases from England; Doyer (3, 4) and Gerritsen and Burgmans (7) from Holland; Neergaard (20) from Denmark; Gadd (6) from Sweden; Noll (21) from Germany; Mogliev and Ryachovsky (18) and Bondartzeva-Monteverde and Vassilievsky (1) from the U.S.S.R.

In Canada, the Ascochyta diseases of peas occur in every province but usually are more destructive in the eastern provinces, especially in Quebec and Ontario. In Western Canada, these diseases are most severe in areas of high rainfall and least prevalent in the semi-arid areas of southern Alberta and the interior of British Columbia. The more serious outbreaks in Canada, reported in the Plant Disease Survey which has been issued annually since 1921 by the Canada Department of Agriculture, may be summarized as follows: Scott, Sask., in 1924; Prince Edward Island, Manitoba, and Kamouraska, Huntingdon, and Chateauguay counties, Que., in 1925; between Lacombe and Olds, Alta., in 1926; Saskatchewan in 1927 and 1928; Edmonton, Alta., Gaspé Co., Que., and York Co., N.B., in 1931; Gaspé Co., Que., and Lacombe, Olds, and Edmonton, Alta., in 1932; Agassiz, B.C., Edmonton, Alta., Scott, Sask., Cap Rouge and Ste. Anne de la Pocatière, Que., in 1934; Indian Head and Swift Current, Sask., in 1935; Kentville, N.S., in 1936; Edmonton and Lethbridge, Alta., and the Gaspé, Que., in 1937; Olds, Alta., Gaspé, Que., and Kentville, N.S., in 1938; East Farnham, Que., in 1940; Queen's Co., P.E.I., in 1941; Lacombe and Olds, Alta., and Charlottetown, P.E.I., in 1943; Beaverlodge, Alta., in 1947.

In Ontario, leaf and pod spot and Mycosphaerella blight are known to occur in all pea-growing areas and have been a limiting factor in pea seed production in the Ottawa Valley and eastern Ontario and to some extent also in the Goderich area of southwestern Ontario and the Georgian Bay area. Gilpatrick and Busch (9) reported leaf and pod spot in many fields in southwestern Ontario during 1949 and 1950.

SEED EXAMINATION

Fungi Isolated from Pea Seed

Published lists of seed-borne micro-organisms include relatively few references to fungus pathogens associated with pea seed. Orton (24) mentions a number of bacterial pathogens, one virus, and the following fungi: *Ascochyta pinodella* Jones, *Ascochyta pisi* Lib., *Erysiphe polygoni* DC., *Macrosporium* sp., *Mycosphaerella pinodes* (Berk. and Blox.) Stone, and *Septoria pisi* West. Doyer (3) refers to *Ascochyta pisi* Lib., *Ascochyta pinodella* Jones, *Mycosphaerella pinodes* (Berk. and Blox.) Stone, *Macrosporium commune* Rab., *Fusarium* spp., *Botrytis cinerea* Pers., and *Cladosporium herbarum* Link. as the fungi pathogenic on pea seed. A more extensive list was published by Neergaard (20) and includes the following species: *Ascochyta pinodella* Jones, *Ascochyta pisi* Lib., *Ascochyta pseudo-pinodella* Bond.-Mont. & Vass., *Botrytis cinerea* Pers., *Cladosporium pisicolum* Snyder, *Corticium solani* (Kühn) Burt, *Erysiphe polygoni* DC., *Fusarium orthoceras*, *Fusarium solani* (Mart.) var. *martii* (App. et Wr. sub species) f. 2 Snyder, *Fusarium* spp., *Mycosphaerella pinodes* (Berk. and Blox.) Stone, *Peronospora viciae* Berk., *Sclerotinia sclerotiorum* (Lib.) Schroet., and *Septoria pisi* West.

When the study of seed-borne fungi was first undertaken at this laboratory it was assumed that the pathogenic importance of many fungi associated with seed was not known and that an attempt should be made to identify as many of these fungi as possible as the first step. The method adopted for their isolation involved the treatment of the seed with a chlorine solution after the method suggested by Wilson (36) and plating the seed on agar media in Petri plates. The reason for adopting this procedure was that the ubiquitous occurrence of air-borne spores of saprophytic fungi of no particular significance in their association with seed would only serve to obscure the presence of truly seed-borne organisms in culture. In surface sterilizing the seed, of course, many important seed-borne pathogens and certain saprophytic forms which might be of consequence in their effect upon germination of the seed and infection of the seedling would also be eliminated. However, as seed treatment has come into such common usage, and as this treatment would eliminate surface-borne organisms in much the same way as the chlorine treatment, the method gives a more accurate representation of the pea-seed associates comparable to conditions to which the seed would be subjected in practice. The elimination of numerous contaminating organisms and germination of the seed on agar media permits the isolation and pure culture study of internally-borne organisms of seeds which would otherwise be obscured if the seed were grown in soil or on blotters. Although it is known that seed-borne bacterial pathogens may be responsible for serious diseases, for example bacterial blight of peas, no record has been kept of the bacteria isolated from seed because of the difficulty of identification in routine testing.

In the list of fungi that follows only those species for which positive identification could be obtained are included.

LIST OF FUNGI ISOLATED FROM PEA SEED

Acremoniella atra (Cda.) Sacc.
Acremoniella verrucosa Togn.
Alternaria tenuis auct.
Ascochyta pinodella Jones
Ascochyta pisi Lib.
Ascodesmis echinulata Bainier
Aspergillus amstelodami (Mangin) Thom & Raper[1]
Aspergillus flavus Link
Aspergillus niger v. Tiegh.
Aspergillus ochraceus Wilhelm
Aspergillus repens (Cda.) DeBary
Aspergillus ruber (Brem.) Thom & Raper
Aspergillus ustus (Bainier) Thom & Raper
Botrytis of the "cinerea" type
Botrytis crystallina (Bon.) Sacc.
Cephalosporium acremonium Cda.
Cephalothecium roseum (Lk.) Cda.
Chaetomium bostrychodes Zopf
Chaetomium cochiliodes Palliser
Chaetomium dolichotrichum Ames
Chaetomium elatum Kze. & Schm.
Chaetomium funicolum Cooke
Chaetomium globosum Kunze
Chaetomium indicum Cda.
Chaetomium murorum Cda.
Chaetomium reflexum Skolko & Groves
Chlamydomyces palmarum (Cooke) Mason
Cladosporium herbarum Fr.
Cladosporium malorum Ruehle
Colletotrichum pisi Pat.
Cunninghamella echinulata Thaxter[2]
Cunninghamella elegans Lendner
Curvularia geniculata (Tr. & Earle) Boedijn
Curvularia inaequalis (Shear) Boedijn
Curvularia lunata (Wakker) Boedijn
Epicoccum neglectum Desm.
Epicoccum purpurascens Ehrenb.
Fusarium avenaceum (Fr.) Sacc.[3]
Fusarium culmorum (W. G. Sm.) Sacc.
Fusarium equiseti (Cda.) Sacc.
Fusarium graminearum Schwabe
Fusarium moniliforme Sheldon
Fusarium oxysporum Schlecht.
Fusarium poae (Peck) Wollenw.
Fusarium scirpi var. *acuminatum* (Ell. & Ev.) Wollenw.
Fusarium semitectum Berk. & Rav. var. *majus* Wollenw.
Fusarium sporotrichioides Sherb.
Gonatobotrys simplex Cda.
Helminthosporium sativum Pammel, King & Bakke
Heterosporium maculatum Klotsch
Lichtheimia corymbifera Vuill.[2]
Lichtheimia ucrainica Naumov
Melanospora papillata Hotson
Melanospora zamiae Cda.
Memnoniella echinata (Rivolta) Galloway
Microascus variabilis Massee & Salmon[4]
Mucor plumbeus Bonorden
Mucor plumbeus Bon. var. *spinescens* Lendner
Mucor racemosus Fres.
Mucor sphaerosporus Hagm.
Mycosphaerella pinodes (Berk. & Blox.) Vestergr. (*Ascochyta pinodes* (B. & Br.) Jones)

[1] Identification of *Aspergillus* and *Penicillium* species by K. B. Raper.
[2] Identification of *Cunninghamella*, *Lichtheimia*, *Mucor*, *Rhizopus*, and *Tieghemella* species by V. M. Cutter, Jr.
[3] Identification of *Fusarium* species by W. L. Gordon.
[4] Identification of *Microascus*, *Petriella*, *Sordaria* and *Thielavia* species by R. F. Cain.

Myrothecium verrucaria (Alb. & Schw.) Dtm.
Nigrospora sphaerica (Sacc.) Mason
Papularia arundinis (Cda.) Sacc.
Papularia sphaerosperma (Pers.) v. Höhn.
Pellicularia filamentosa (Pat.) Rogers
Penicillium cyclopium Westling[1]
Penicillium kapuscinskii Zaleski
Penicillium terrestre Jensen
Penicillium verrucosum Dierckx.
Periconia circinata (Mangin) Sacc.
Periconia pycnospora Fres.
Petriella asymmetrica Curzi[4]
Pullularia pullulans (DeBary) Berkhout
Oospora lactis Fresen.
Rhizopus cohnii Berl. & deTon.[2]
Sclerotinia sclerotiorum (Lib.) DeBary
Septoria pisi Westend
Sordaria fimicola (Rob.) Ces. & DeNot.[4]
Sordaria inaequalis Cain
Stachybotrys atra Cda.
Stemphylium botryosum Wallr.
Stemphylium consortiale (v. Thüm.) Groves & Skolko
Syncephalastrum fuliginosum Bainier
Thielavia basicola Zopf[4]
Thielavia sepedonicum Emmons
Tieghemella italica (Per. & Cost.) Naumov[2]
Trichocladium asperum (Cda.) Harz.
Trichoderma viride Pers. ex Fries
Verticillium albo-atrum Reinke & Berthold

Summary of Pea Seed Examinations for Ascochyta spp.

During the period 1939-1950, almost 5000 samples of pea seed were examined for the presence of seed-borne fungi according to the procedure mentioned above. Of the domestic samples examined, almost 3000 samples were of commercial grade. The remainder had been submitted for approval of application for foundation, elite, registered, or certified status and, in many cases, were rejected because of the presence of seed-borne pathogens above an allowable level arbitrarily established but subject to change in accordance with the supply of available seed stocks. The three species of *Ascochyta* were the most prevalent of the pathogenic fungi isolated and were responsible for most rejections. The results of the laboratory examination of domestic pea seed samples are summarized in Table 1.

The most striking fact shown in Table 1 is that 51 per cent of all samples tested were infected by *Ascochyta* spp. to a greater or lesser degree and that 18 per cent of the samples were infected to the extent of over 10 per cent of the seed. Seed grown in Eastern Canada, particularly in Quebec and eastern Ontario, included a high percentage of infected samples as compared with western-grown seed. Furthermore, a greater proportion of the infected samples of eastern origin were heavily infected with *Ascochyta* spp. (i.e. over 10 per cent of the seeds infected in a given sample). For example, of the infected samples from Quebec, 50 per cent were classified as heavily infected. Similarly, 34 and 41 per cent of the infected samples from eastern Ontario and western Ontario, respectively, were heavily infected, whereas only 19 and 12 per cent, respectively from Alberta and British Columbia were heavily infected. The higher incidence of disease in the east can be attributed to the more favourable moisture conditions and perhaps, in part, to the fact that pea cultivation has been practised for a longer time in the east with resulting accumulation of diseased pea seed stocks.

TABLE 1.—RESULTS OF PEA SEED EXAMINATION FOR PRESENCE OF *Ascochyta* SPP. DURING 1939-1950, BY DISTRICTS IN CANADA

District	Number of samples	Uninfected samples	Moderately infected samples[1]	Heavily infected samples[2]	Total infected samples
		%	%	%	%
Maritimes	2	50	50	0	50
Quebec	288	33	33	34	67
Eastern Ontario	1424	39	40	21	61
Western Ontario	1782	48	31	21	52
Manitoba	279	65	27	8	35
Saskatchewan	479	46	38	16	54
Alberta	211	79	17	4	21
British Columbia	264	83	15	2	17
Canada	4729	49	33	18	51

[1] 10 per cent or less of the seeds in a sample infected with *Ascochyta* spp.
[2] Over 10 per cent of the seeds in a sample infected with *Ascochyta* spp.

By comparing the incidence of infection in foundation and registered seed, it was apparent that foundation seed was much less frequently infected and to a lesser degree. Only 8 per cent of the infected foundation seed samples were classified as "heavily" infected as compared with 30 per cent of the registered grades and 43 per cent of the commercial grade. The fact remains that over half of the domestic samples of pea seed examined were infected and in some instances the sample contained as high as 70 per cent of the seed infected with *Ascochyta* spp. Of the infected samples, it was found that 85 per cent were infected with *A. pisi*, 27.5 per cent with *A. pinodes*, and 10 per cent with *A. pinodella*. Sometimes a sample was found to be infected by two or even all three species. Furthermore, of the samples infected by *A. pisi*, 37 per cent were found to be heavily infected. By contrast, only 13 per cent of the samples infected by *A. pinodes* and only 4.5 per cent infected by *A. pinodella* were classified as heavily infected.

In 1948 an attempt was made to assess Canadian-grown pea seed in comparison with imported seed. The results of these tests are summarized in Table 2.

It may be seen in Table 2 that 27 per cent of the Canadian samples were infected with *Ascochyta* spp., but it must be noted also that some of the samples were from eastern-grown crops. Of the infected Canadian samples, 73 per cent were infected with *Ascochyta pisi*, 38 per cent with *A. pinodes*, and 23 per cent with *A. pinodella*. *Ascochyta pisi* was responsible for the high degree of infection in the 9 samples that were found to be heavily infected. The samples from the United States were all western-grown and only 6 per cent of them were found to be infected with *Ascochyta* spp.

TABLE 2.—RESULTS OF PEA SEED EXAMINATION FOR PRESENCE OF *Ascochyta* SPP. OF DOMESTIC AND FOREIGN SEED SAMPLES RECEIVED IN 1948

Source[1]	Number of samples	Uninfected samples	Moderately infected samples[2]	Heavily infected samples[3]	Total infected samples
		%	%	%	%
Canada	96	73	18	9	27
U.S.A.	50	94	4	2	6
United Kingdom	5	0	100	0	100

[1] Canadian samples included both eastern- and western-grown samples. Samples from the U.S.A. were grown in northwestern states and California. Samples from the United Kingdom may have been grown in continental Europe but no information available.
[2] 10 per cent or less of the seeds in a sample infected with *Ascochyta* spp.
[3] Over 10 per cent of the seeds in a sample infected with *Ascochyta* spp.

Only one sample was heavily infected and this by *A. pinodella*. This finding is in keeping with the report of the importance of *A. pinodella* in Washington state by Gould (11). Only 5 samples were available from the United Kingdom and all were found to be infected. Moore (19) reported that leaf and pod spot was widely distributed in southern England and rejection of commercial seed for export amounted to 22 per cent of 1000 samples examined over a period of 17 years. In general, comparing the results of the pea seed examinations outlined above with those reported earlier by Jones (16), the similarity of both distribution and incidence of Ascochyta infection of pea seed is evident.

VARIETAL RESISTANCE

From a review of the literature on varietal resistance to the Ascochyta diseases, one would probably be correct in the conclusion that there are no pea varieties available that possess a practical degree of resistance combined with acceptable agronomic or horticultural quality. In 1926 Gilchrist (8) reported that no variety of pea had been found to be immune to footrot (*Ascochyta* sp.). Jones (16) tested a large number of varieties of commercial peas by inoculation with 3 isolates of *M. pinodes*, 4 isolates of *A. pisi* and 3 isolates of *A. pinodella*. None of the varieties was immune although some were only slightly susceptible, a probable crop reduction of 10 to 30 per cent. Fewer varieties showed resistance to *A. pinodella* than to *M. pinodes*, and fewer to *M. pinodes* than to *A. pisi*. Ogden (22) tested the progeny of crosses between Austrian Winter field pea and disease-resistant garden or canning pea varieties, but failed to find a strain of peas resistant to *M. pinodes*. Seal (26) concluded that there was no marked difference among the many varieties that he tested by greenhouse inoculation, but that in the field, winter hardy varieties showed less disease. Selections of Austrian Winter pea were best. Weimer (34, 35) found the Austrian Winter field pea highly resistant to *A. pisi*, but less resistant to *M. pinodes* and *A. pinodella*. Gerritsen and Burgmans (7) mention two varieties, Mansholt's Hybrid Extra Short and Nunheim's Hekkensluiter, as noteworthy for their resistance. Noll (21) considered that 4 garden and

2 field varieties showed some resistance to *A. pinodella*, but that fully resistant varieties still had not been found. Mogliev and Ryachovsky (18), by selection from 500 pure lines of the variety Victoria Heine, retained 6 lines as showing resistance to *A. pisi*. Gould (11) stated that none of the varieties which he tested was immune to *A. pinodella* although a number of varieties possessed considerable resistance. Ferguson, Lyall and Jasmin (5) mention that there is a high degree of resistance to *A. pisi* in selections A-100, A-101, Austrian Winter, and the subspecies *elatius* and *faliegi* of *Pisum sativum*. Wark (31) tested over 200 varieties and strains of peas for resistance to *A. pisi* and found that Austrian Winter was the least susceptible of the varieties tested. Gilpatrick and Busch (10) report that the varieties O.A.C. 181, Scotch, and A-100 appear to have some resistance to *A. pisi*.

In assessing the varietal resistance or susceptibility of pea varieties to Ascochyta diseases a number of points must be kept in mind. In the first place we are concerned with three distinct species which differ in their pathogenicity, *A. pinodella* and *M. pinodes* appearing to be more virulent than *A. pisi*. Secondly, the existence of physiologic forms within each species must not be overlooked. Jones (16) must have considered this possibility in selecting his isolates from widely separated geographic regions. Bondartzeva-Monteverde and Vassilievsky (1) claimed the existence of 5 forms of *A. pisi* and 3 forms of *M. pinodes*, differing from one another in cultural characters and pathogenicity. Gilpatrick and Busch (10) reported that there were at least 3 physiologic races of *A. pisi* based on the pathogenicity of 7 isolates on 8 varieties of peas, and on *Vicia villosa* and *Vicia villosa* var. *glabrescens*. The results of our own studies, as yet unpublished, show that there are more physiologic forms than has been indicated thus far. Thirdly, the method of inoculation and conditions of incubation may possibly affect the incidence of disease, for example, inoculation of the seed as compared with spraying the young seedlings, greenhouse as compared with field test, etc. Similarly, the age of the plant and stage of development must be taken into consideration. Wark (30) found that seedlings were more resistant than older plants and that late varieties were usually more resistant than early ones. Furthermore, he found that Austrian Winter was highly resistant to stem girdling, less resistant to leaf spotting, but susceptible to pod spotting. In spite of this, Austrian Winter has been reported by several other investigators as a resistant variety. Finally, the necessity of repeated selection within so-called "pure varieties" implies considerable heterozygosity for factors affecting resistance.

Taking into account the possible sources of variation mentioned above, a large number of pea varieties have been tested in the field during the last 5 years. Inoculum was prepared according to the method suggested by Weimer (33) using sterilized pea seed as a medium for inoculum increase. Ten isolates of *A. pisi* were used and mixed prior to inoculation. The pea seed upon which the fungus had been grown was placed on the surface of the soil at the base of the plants just after emergence, by mixing the inoculum in water and pouring it over the young plants. The infected pea seed thus provided a constant source of inoculum throughout the growing period whenever weather conditions were favourable for infection. It was

TABLE 3.—FIVE-YEAR AVERAGE OF SEED INFECTION FROM PEA VARIETIES INOCULATED IN THE FIELD WITH MIXTURE OF 10 ISOLATES OF *Ascochyta pisi*

Variety	Seed infection	Variety	Seed infection
	%		%
Alaska	2.0	Laxtonian	15.2
A-100	2.6	Pride	15.8
Thos. Laxton	5.8	Onward	16.0
Advancer	6.6	Tall Telephone	17.0
Super Alaska	7.5	Canadian Beauty	17.0
Climax	8.0	Foreign 18	17.2
Foreign No. 3	8.2	Rouke	17.7
Chancellor	8.6	O.A.C. 181	18.0
Superior W.R.	9.5	Teton	18.2
Perfection	9.6	Little Marvel	18.6
Arthur	9.8	Kootenay	19.2
Wisconsin Early Sweet	10.6	Glacier	19.4
Tiny	11.0	Delwiche Commando	21.6
Valley	11.0	Laxal	24.0
Wyola	11.0	Giant Stride	24.4
Alton	11.6	Alderman	24.6
Swonder	12.0	Laxton's Progress	26.2
Polish	13.0	Miracle	27.0
Smalton	13.0	Engress	28.6
Laxanney	13.5	Stratagem	29.4
Early Blue	14.2	Entel	31.2
Director	14.6	Lincoln	32.4

soon recognized that seedling mortality, unless severe, had little effect upon yield and that the amount of leaf, stem, and pod spotting was not closely correlated with infection in seed produced by these plants. It is believed that infection of the seed is dependent upon weather conditions during or after the pods have matured, when symptoms of pod infection are difficult to discern. Provided conditions for disease development were favourable, early pod infection resulted in failure to mature seed. Heavily diseased plants often produced relatively disease-free seed and conversely, apparently healthy plants produced heavily infected seed. Since our chief concern was in the production of disease-free seed, this criterion was used as a measure of resistance, and repetition over a five-year period provided against seasonal variation. Only known commercial varieties are included in Table 3 which lists the varieties in descending order of resistance. Seed produced by the varieties under test were plated on pea agar to determine the extent of seed infection.

The variety Thos. Laxton and many of the varieties derived from it are known to be susceptible to Ascochyta diseases and have been discarded or are very little used in commercial production in Eastern Canada for this reason. Yet in our field tests, summarized in Table 3, Thos. Laxton appears to be highly resistant to *A. pisi* seed infection. No explanation for this apparent resistance of Thos. Laxton can be suggested except the possibility that the isolates used as inoculum did not include forms of *A. pisi* virulent for this variety or that a resistant selection of Thos. Laxton was tested. The remaining varieties listed appear in approximately their expected positions for resistance, with the field varieties somewhat less susceptible than most garden varieties.

ACKNOWLEDGMENT

To the late G. A. Scott, under whose direction this work was performed until 1946, we are indebted for much of the data reported here. We must assume full responsibility for interpretation and conclusions derived from these data. We also wish to acknowledge the participation of W. C. Broadfoot, Miss M. E. Elliott, Miss R. Mackay, Mrs. V. R. Wallen, W. Bell and many others in the testing of the seed samples and in the field trials. We are indebted to officers of the Plant Products Division of the Canada Department of Agriculture; the Canadian Seed Growers' Association; L. H. Lyall, Horticulture Division; P. R. Cowan, Cereal Crops Division; and W. G. Wilson, Canners Seeds Ltd., Wellington, Ont., for providing most of the seed used for the tests.

REFERENCES

1. Bondartzeva-Monteverde, V. N., and N. I. Vassilievsky. [Ascochytosis of the pea]. U.S.S.R. Acad. Sci. Press. Moscow. 1937. *In* Rev. Appl. Myc. 17 : 427-428.
2. Butler, F. C. Diseases of peas carried in the seed. Agr. Gaz. N.S.W. 60 : 294-295. 1949.
3. Doyer, L. C. Manual for the determination of seed-borne diseases. International Seed Testing Assoc., H. Veenman & Sons, Wageningen, Netherlands. 1938.
4. Doyer, L. C. Several seed-borne fungus diseases and methods for identifying them in seed testing. Trans. Brit. Mycol. Soc. 30 : 67-73. 1948.
5. Ferguson, W., L. H. Lyall, and J. J. Jasmin. Vegetable crops. Can. Hort. Council Comm. on Hort. Res., Ann. Rept. 28 : 9-10. 1950.
6. Gadd, Ivar. Hot-water treatment, a new method of controlling *Ascochyta* spp. on pea seeds. Proc. International Seed Testing Assoc. 16 : 1-94. 1950.
7. Gerritsen, J. D., and H. Burgmans. [Ascochyta diseases of peas (preliminary study on the susceptibility of field and garden peas)]. Tijdschr. Pl. Ziekt. 46 : 57-82. 1940.
8. Gilchrist, G. G. The nature of resistance to footrot caused by *Ascochyta* sp. and some other fungi in the epicotyl of the pea. Phytopath. 16 : 269-276. 1926.
9. Gilpatrick, J. D., and L. V. Busch. Pea diseases in southwestern Ontario in 1949 and 1950. Pl. Dis. Reporter 34 : 340. 1950.
10. Gilpatrick, J. D., and L. V. Busch. Studies on the pathogenicity of different isolates of *Ascochyta pisi* Lib. Pl. Dis. Reporter 34 : 383-387. 1950.
11. Gould, C. J. *Ascochyta pinodella* footrot of peas in western Washington. Phytopath. 39 : 947-949. 1949.
12. Hare, W. W., and J. C. Walker. Ascochyta diseases of canning peas. Wis. Agr. Exp. Sta. Res. Bull. 150. 1944.
13. Horn, N. L., and J. G. Atkins. Pea and vetch diseases in Louisiana. Phytopath. 40 : 788-789. 1950. (Abstract).
14. Jauch, C. Resoluciones y resumenes de los trabajos presentados. Primera Reunion Argentina de Agronomia, Abril, 1941. *In* Rev. Appl. Myc. 21 : 185-186. 1942.
15. Jones, F. R., and M. B. Linford. Pea disease survey in Wisconsin. Wis. Agr. Exp. Sta. Res. Bull. 64. 1925.
16. Jones, L. K. Studies of the nature and control of blight, leaf and pod spot, and footrot of peas caused by species of *Ascochyta*. N.Y. (Geneva) Agr. Expt. Sta. Bull. 547 1927.
17. Linford, M. B., and R. Sprague. Species of *Ascochyta* parasitic on the pea. Phytopath. 17 : 381-397. 1927.
18. Mogilev, L. M., and N. A. Ryachovsky. [Pure lines of the pea variety 'Victoria Heine' resistant to *Ascochyta pisi* Lib.]. C. R. Pan-Sov. V. I. Lenin Acad. Agr. Sci., Moscow 6 : 11-12. 1941. *In* Rev. Appl. Myc. 22 : 6. 1943.
19. Moore, W. C. Report on fungus, bacterial and other diseases of crops in England and Wales for the years 1933-1942. Ministry of Agr. & Fisheries Bull. 126. 1946.
20. Neergaard, P. Seed-borne fungous diseases of horticultural plants. Comtes-rendus de l'Assoc. Internat. d'Essais de Semences 1 : 47-71. 1940.

21. Noll, W. Über weitere Befallsymptome und Massnahmen zur Verhütung von Schäden durch *Ascochyta pinodella* Jones, *A. pisi* Lib. und *Mycosphaerella pinodes* (Berk. u. Blox,) Stone bei Erbsen. Zeitschr. f. Pflanzenkr. 50 : 49-71. 1940.
22. Ogden, H. P. Winter pea breeding. Tenn. Agr. Expt. Sta. Ann. Rep. 48 : 11-12. 1936.
23. Ogilvie, L., and B. O. Mulligan. Progress report on vegetable diseases—IV. U. of Bristol Agr. & Hort. Res. Sta. Ann. Rept. 1932 : 103-120. 1932.
24. Orton, C. R. Seed-borne parasites, a bibliography. W. Va. Agr. Expt. Sta. Bull. 245. 1931.
25. Reinking, O. A. Distribution and relative importance of various fungi associated with pea-rot in commercial pea-growing areas in New York. N.Y. Agr. Expt. Sta. Tech. Bull. 264. 1942.
26. Seal, J. L. The Mycosphaerella disease of winter peas, and diseases of winter peas and vetches caused by *Ascochyta* species. Ala. Agr. Expt. Sta. Ann. Rept. 48 : 24-25. 1938.
27. Starr, G. H. A study of diseases of canning crops (peas and corn) in Minnesota. U. of Minn. Agr. Expt. Sta. Tech. Bull. 89. 1932.
28. Stubbs, L. L. Ascochyta blight of field and garden peas. J. Dept. Agr., Victoria 40 : 260-262. 1942.
29. Walker, J. C., and W. W. Hare. Pea diseases in Wisconsin in 1942. Wis. Agr. Expt. Sta. Res. Bull. 145. 1943.
30. Wark, D. C. The susceptibility of peas to four diseases occurring naturally in the Australian capital territory. J. Aust. Inst. Agr. Sci. 16 : 32-33. 1950.
31. Wark, D. C. The inheritance of resistance to *Ascochyta pisi* Lib. in *Pisum sativum* L. Aust. J. Agr. Res. 1 : 382-390. 1950.
32. Weaver, L. O. Diseases of peas in Pennsylvania. Seed World 59 (11) : 96-98. 1946.
33. Weimer, J. L. Methods of value in breeding Austrian winter field peas for disease resistance in the south. Phytopath. 30 : 155-160. 1940.
34. Weimer, J. L. Austrian winter field pea diseases and their control in the south. U.S. Dept. Agr. Circ. 565. 1940.
35. Weimer, J. L. Resistance of *Lathyrus* spp. and *Pisum* spp. to *Ascochyta pinodella* and *Mycosphaerella pinodes*. J. Agr. Res. 75 : 181-190. 1947.
36. Wilson, J. K. Calcium hypochlorite as a seed sterilizer. Amer. J. Bot. 2 : 420-427. 1915.

ROOT-LESION NEMATODES ASSOCIATED WITH ROOT DECLINE OF SMALL FRUITS AND OTHER CROPS IN BRITISH COLUMBIA[1]

J. E. Bosher[2]

Plant Pathology Laboratory, Saanichton, B.C.

[Received for publication January 28, 1954]

ABSTRACT

Species of nematodes belonging to the genera *Pratylenchus*, *Paratylenchus*, *Xiphinema*, *Criconemoides*, and *Criconema*, are associated with decaying roots of strawberry, loganberry, and raspberry plants in certain plantations in British Columbia, and are an important factor in declining yields.

Pratylenchus penetrans, *Xiphinema americanum*, *Criconemoides curvatum* and *Criconemoides* sp., and *Criconema* sp. are reported for the first time in Canada.

INTRODUCTION

A general decline has been observed in the vigour and yield of strawberries, loganberries and raspberries in many plantations in Vancouver Island and the Fraser Valley of British Columbia, particularly in districts where these fruits have been under cultivation for a long time. The most noticeable symptoms of decline are unthriftiness and occasional death of plants. A survey showed that the roots of the plants were frequently necrotic and, in many cases, a large proportion of the root systems was dead. As virus or above-ground disorders obviously were not responsible for the condition, an investigation of the roots of affected plants was undertaken. Nematodes, some of which belong to hitherto unreported genera and species, were found in large numbers in the roots or root zone in many plantations. The relative importance of the organisms found to be associated with the root-rot complex cannot be definitely evaluated at the present time, but there is little doubt that nematodes play a very important role in root degeneration.

NEMATODES OF ECTO-PARASITIC TYPE

Nematodes of the genus *Paratylenchus* have been discovered in large numbers in the root zone of loganberries (7) and raspberries, and in one plantation of English holly (*Ilex aquifolium*) near Victoria, B.C. Their presence appears to be associated with a slow, progressive decline in vigour, similar to that in figs as described by Thorne and Allen (8). Specimens of *Paratylenchus* attached to the fine rootlets have been observed frequently, and the rootlets usually show a brownish discoloration along the whole length of the roots, apparently as a result of nematode attack.

Xiphinema americanum Cobb., considered by Christie (2) as one of four ecto-parasitic nematodes of major importance in the Southeastern United States, has also been frequently found in the course of root examination of loganberries, raspberries, and strawberries in British Columbia. An occasional specimen has been observed with its stylet inserted into a living

[1] Contribution No. 1362 from the Botany and Plant Pathology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Assistant Plant Pathologist.

root, but the specific role of this nematode is difficult to assess, since it has usually been found in association with *Pratylenchus* and *Paratylenchus*.

Other ecto-parasitic nematodes of probable importance in the root decline complex include *Criconemoides* sp. and *Criconema* sp. in association. These nematodes were discovered recently on the roots of loganberries in a plantation at Brentwood, Vancouver Island, that had been ploughed up because of its declining vigour. In this case, the fine feeder roots of the plants were in short bunchy masses close to the crown of the plants. One other species of *Criconemoides* discovered in soil from a nursery in Victoria and identified as *C. curvatum* Raski was transferred to greenhouse cultures of sweet peas, red clover, and dwarf beans (*Phaseolus vulgaris* var. Masterpiece). Specimens of *C. curvatum* have been observed feeding along the young roots of these plants, usually a short distance from the tips. It appears probable that injury of this type would cause the restricted root growth observed in the case of the loganberries. Observations by Chitwood (1) and Machmer (6) suggest that *Criconemoides* spp. are a major factor in the decline of plants of various types; they may possibly be responsible for the apparent senility of loganberry plants in the Brentwood plantation.

NEMATODES OF ENDO-PARASITIC TYPE

Characteristic lesions caused by species of *Pratylenchus* are found frequently on the roots of strawberry, raspberry, loganberry, and other crops. Numerous microscopic observations of diseased roots taken from unthrifty plants in several localities have shown that the roots contained large numbers of mature adults, larvae, and eggs of *Pratylenchus*. Previous reports (3, 4, 5) have recorded the presence of *P. pratensis* de Man, in crops in British Columbia, but examinations made recently show that *P. pratensis* is the species most commonly found in strawberries and raspberries in the Hatzic and Abbotsford districts of the Fraser Valley, while *P. penetrans* Cobb has been identified most frequently in loganberries, raspberries, and strawberries on Vancouver Island, and on tulips and narcissus in the Cloverdale district of the Fraser Valley. This is believed to be the first record of the occurrence of *P. penetrans* on these crops in Canada.

Host-range studies of these two species of *Pratylenchus* in greenhouse cultures show that they will readily enter the roots of seedling oats, rye, barley, and red and alsike clover, often used as rotation or green manure crops by fruit and bulb growers. It appears probable that these crops, when used as winter cover, serve to maintain large populations of *Pratylenchus*.

DISCUSSION

Although the observations recorded show that root-lesion nematodes occur in many cases in large numbers in the fruit-growing areas of southern British Columbia and are undoubtedly an important factor in the decline of plantations of small fruits, frequently isolations of parasitic fungi from diseased roots suggest that the root-rot problem is a complex, in which soil type, drainage, and cultural practices, as well as fungi and nematodes, play a part. Attention is drawn to the probable dissemination of plant-

parasitic nematodes from infested plantations on the roots of strawberry runners, loganberry tips, and raspberry suckers into areas that are at present apparently free of infestation.

ACKNOWLEDGMENTS

Sincere thanks are extended to A. D. Baker and S. A. Sher, Entomology Division, Ottawa, Gerald Thorne, U.S.D.A. Division of Nematology, Salt Lake City, Utah, and D. J. Raski, University of California, Berkeley, California, for confirmation of the identity of some of the nematodes recorded in this paper.

REFERENCES

1. Chitwood, B. G. Ring nematodes (*Criconematinae*). A possible factor in decline and replanting problems of peach orchards. Proc. Helm. Soc. Wash. 16 : 1. 1949.
2. Christie, J. R. Ectoparasitic nematodes of plants. Phytopath. 42 : 9. 1952.
3. Hastings, R. J., Wm. Newton, and G. Steiner. Root decline of narcissus. Pl. Dis. Rept. 16 : 112-113. 1932.
4. Hastings, R. J. Miscellaneous notes on some nematode diseases of plants in British Columbia. Pl. Dis. Rept. 19 : 26. 1935.
5. Hastings, R. J., and J. E. Bosher. A study of the pathogenicity of the meadow nematode and associated fungus *Cylindrocarpon radicicola* Wr. Can. J. Res., *C*, 16 : 225-229. 1938.
6. Machmer, J. H. *Criconemoides* sp. A ring nematode associated with peanut yellows. Pl. Dis. Rept. 37 : 3. 1953.
7. McKeen, W. E. Loganberry decline on Vancouver Island. Pl. Dis. Rept. 37 : 6. 1953.
8. Thorne, G., and M. W. Allen. *Paratylenchus hamatus* n. sp. and *Xiphinema index* n. sp. Two nematodes associated with fig roots, with a note on *P. anceps* Cobb. Proc. Helm. Soc. Wash. 17 : 1. 1950.

ALUMINUM FOIL PLANTING BOXES FOR GREEN-HOUSE EXPERIMENTS[1]

W. G. BENEDICT[2] AND W. B. MOUNTAIN[2]

Science Service Laboratory, Harrow, Ontario

[Received for publication January 12, 1954]

ABSTRACT

Small, watertight, aluminum foil planting boxes arranged in metal trays were used to advantage in increasing the number of treatments and replications in studies involving the use of standard Wisconsin soil-temperature tanks.

In the investigation of the effects of soil temperatures on plant diseases, the standard 8-can Wisconsin soil-temperature tank is commonly used, but presents a problem when replications sufficient for statistical analysis are required. To overcome this problem in the past, metal trays have been substituted for the cans (1). With the trays it is virtually impossible to remove individual plants with their root systems intact. Moreover, the number of treatments is limited by the number of trays, usually two per tank.

In a recent study of a root rot of wheat, the soil-temperature experiments necessitated not only a sufficient number of replications for analysis, but also a periodic examination of complete root systems from each treatment. Initially it was considered feasible to use 4-in. clay pots with the drainage hole plugged, but the two trays in each tank could accommodate only 8 pots each. This number of pots was inadequate. A search was then made for a suitable material with which to make small, water-tight soil containers of the desired size, strength, and cost, which would fit inside the metal trays and allow several soil treatments to be studied simultaneously. Plant bands were unsuitable because they were not watertight and plant roots and organisms in the soil could migrate easily between contiguous containers. Ordinary light-weight aluminum foil seemed best to fit the needs of the experiment.

It was found that 30 aluminum foil boxes, each 3″ by 3″, by 4″ deep, would fill one tray (Figure 1), thus allowing 60 such boxes to each soil-temperature tank. These boxes were made by folding an 8″ × 12″ piece of aluminum foil around a 3″ × 3″ wooden form with a small hole bored through the centre, as shown in Figure 2. A piece of cellulose tape was wrapped around the folded box on the form before the box was removed. These boxes proved to be watertight. When placed in the trays, they were filled with soil by means of a trowel and metal funnel as shown in Figure 2. The boxes could be made at the rate of one per minute and cost less than one cent each for the materials. Five 2-weeks-old wheat plants growing in one of these aluminum foil planting boxes are shown in Figure 2.

The simple aluminum foil boxes described above increased the capacity of the common Wisconsin soil-temperature tanks to the point where results could be analysed and the authors felt that the method might be

[1] Contribution No. 1350 from the Botany and Plant Pathology Division, Science Service, Department of Agriculture, Ottawa, Canada.
[2] Associate Plant Pathologists.

FIGURE 1. Aluminum foil planting boxes fitted in a metal tray that is commonly used in Wisconsin soil-temperature tanks.

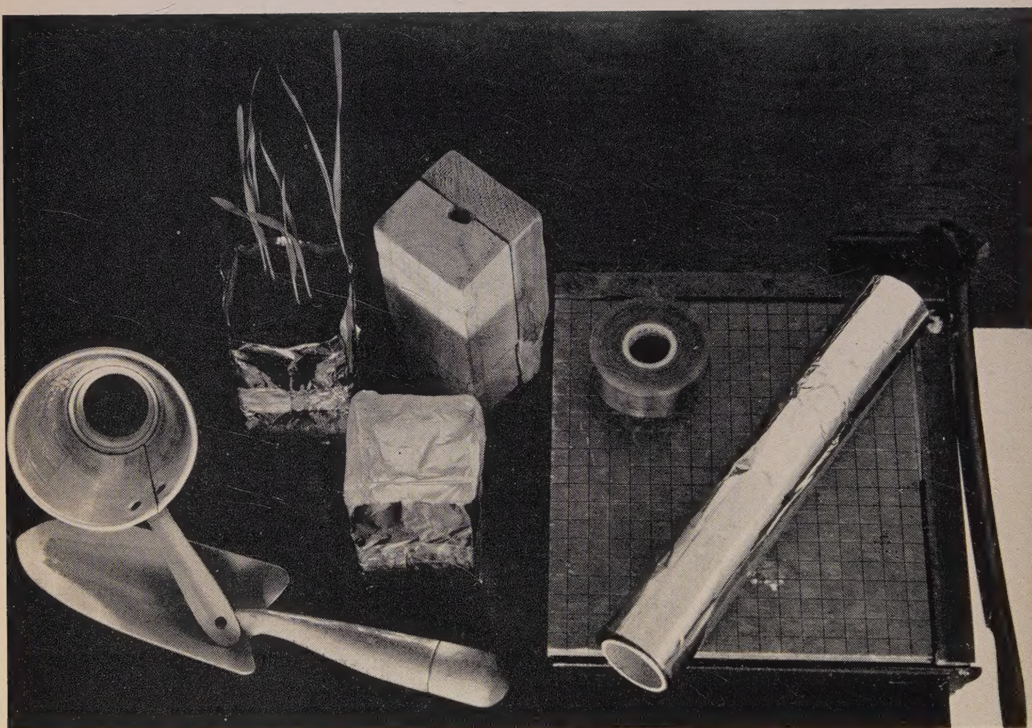

FIGURE 2. Materials used to make and fill aluminum foil planting boxes.

adopted for use in many other experiments involving the study of soil micro-organisms. No signs of phytotoxicity have been noticed as a result of their use, nor has there appeared to be any effect upon population of soil micro-organisms.

REFERENCE

1. Gorenz, A. M., R. H. Larson, and J. C. Walker. Factors affecting pathogenicity of pink root fungus of onions. J. Agr. Res. 78 : 1-18. 1949.